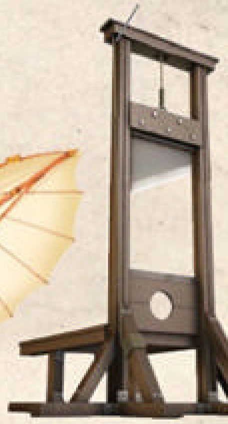
NEW

ANCIENT HISTORY · BUILDINGS & LANDMARKS · WEAPONS & WAR

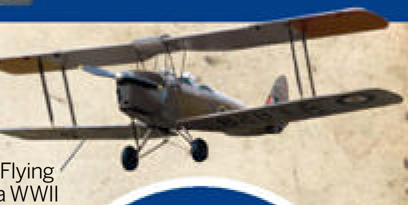
Horse armour explained

What were velociraptors really like?

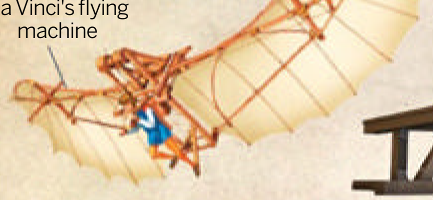

How was the guillotine invented?

How did the gramophone work?

Soldiers of Ancient Rome


Flying a WWII plane

OVER 250 MILLION YEARS OF HISTORY


Da Vinci's flying machine

The biggest prehistoric predators

HOW IT WORKS BOOK OF

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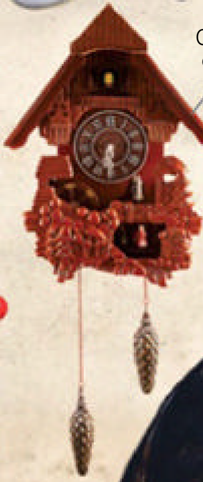
The American Sherman army tank

Inside St Mark's Basilica

Who were the fearsome Celts?

Trench warfare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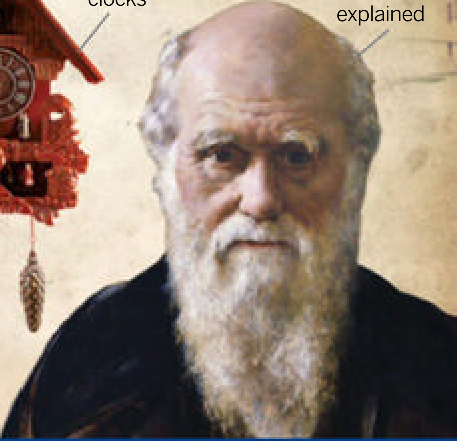
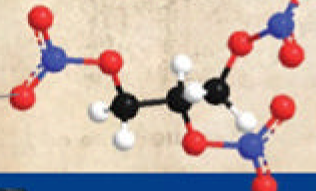

Darwin's theories explained

How did Native Americans fight?


The development of explosives

INDUSTRY & INVENTIONS · INFLUENTIAL FIGURES · PREHISTORIC

Welcome to

HOW IT WORKS

BOOK OF

INCREDIBLE HISTORY

Have you ever wondered what Ancient Rome invented? What life would have been like in the time of the dinosaurs? How dynamite was invented? What it was like to be a Zulu warrior or a musketeer? With current technological advancements it is easy to forget the wars, the discoveries, the creatures and the people that have led us to where we are today. This revised edition celebrates the past and takes us on a journey back in time through some of the ages, customs and traditions that shaped the world we live in, and the lasting legacies and monuments that we cherish to this day. Covering the ancient world, the iconic buildings and landmarks scattered around the globe, ground-breaking weapons and warfare, the inventions that changed the world, the influential visionaries from the past, and prehistoric creatures that once roamed Earth, there's something for everyone to learn about and enjoy. Every subject is accompanied by stunning illustrations and marked diagrams so that you can best understand the topic covered in perfect detail. So, turn the page and let's bring history to life!

HOW IT WORKS
BOOK OF
INCREDIBLE HISTORY

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HOW IT WORKS BOOK OF INCREDIBLE HISTORY

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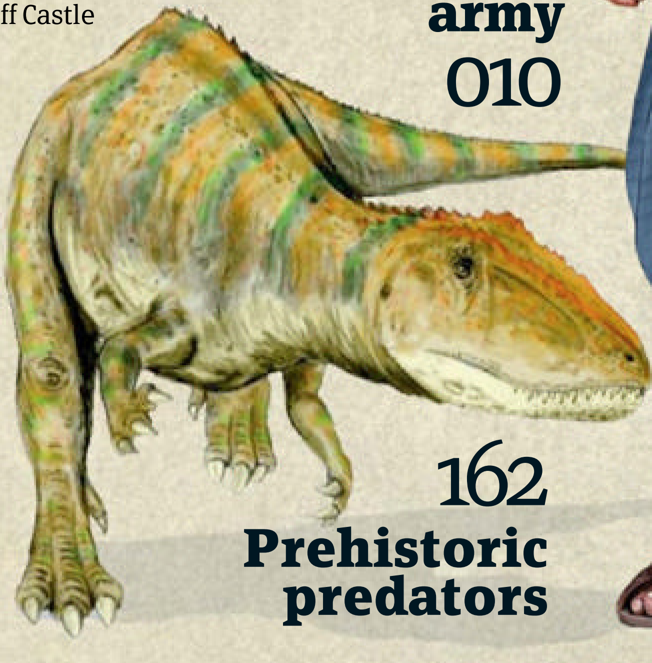

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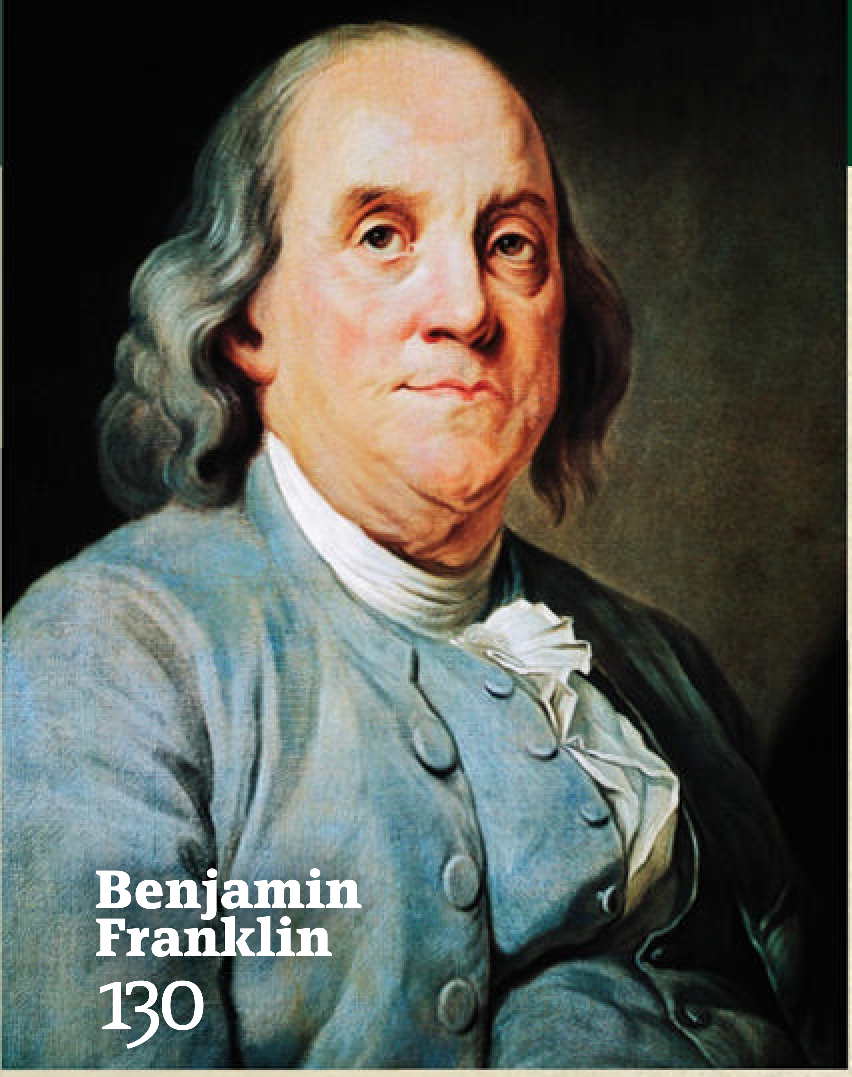

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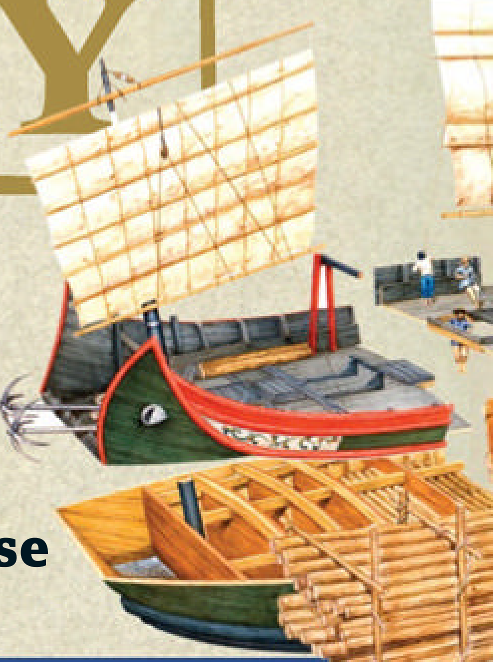

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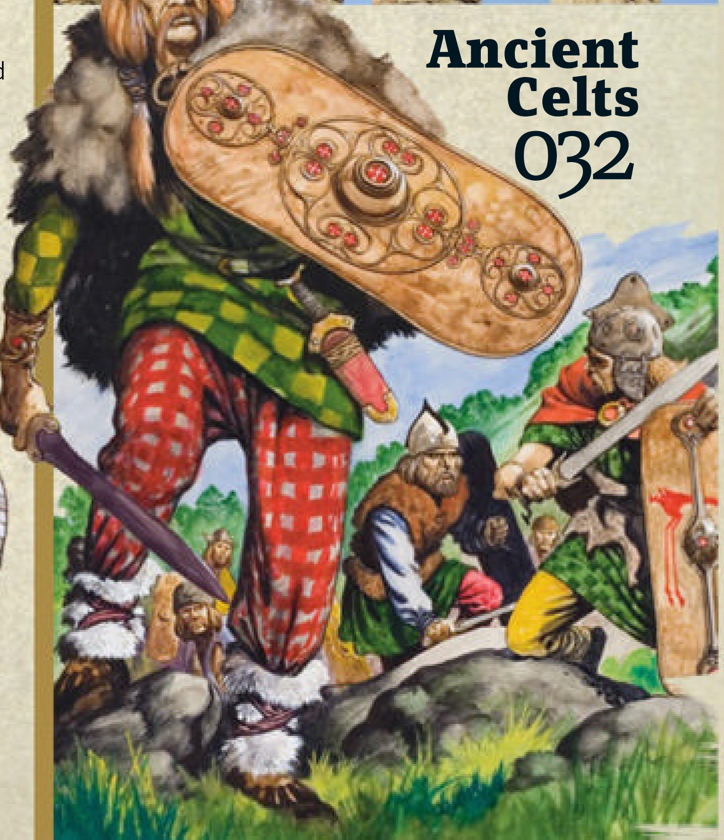

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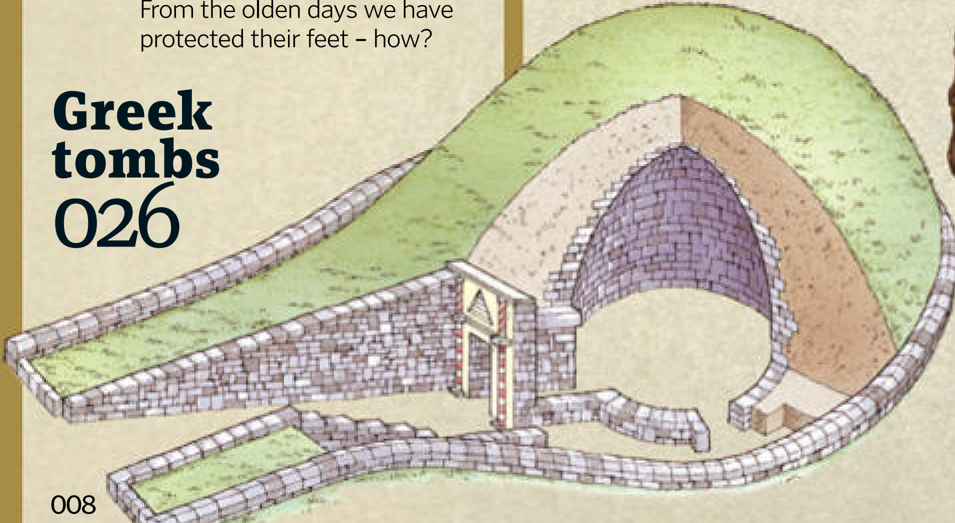

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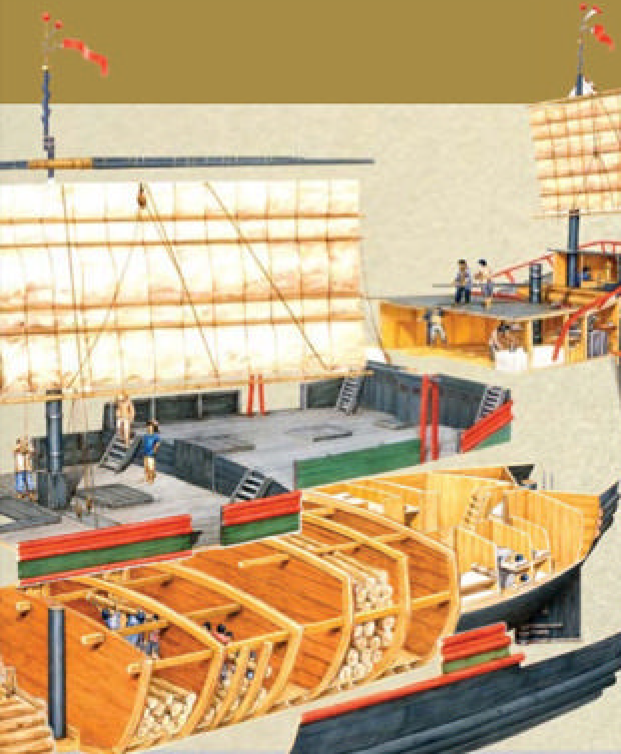

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INVENTIONS OF ANCIENT ROME

How the Romans changed the world you live in

Perhaps the greatest of all the ancient civilisations, the Roman Empire represented the age of classical antiquity and helped create the world we live in today. The massive engineering projects that were undertaken and the advances in medicine and society ensure Roman influence can still be felt now. For example, concrete and cement were first popularised in Ancient Rome, as was a type of central heating known as a hypocaust.

One of the most remarkable traits of all though, was the ability for the Romans to work all their schemes and inventions into fully functioning cities within an extensive empire. Rome itself was a bustling metropolis that no other civilisation matched in prosperity and size for centuries afterward. Nowhere else in the ancient world had grand shopping centres like Trajan's Market, specialised landfill sites such as Monte Testaccio or extensive sewer networks like the Cloaca Maxima. They were also famously proficient at town planning and building large structures.

Home life was revolutionised under the Romans. Also, as is well known, the army was an all-conquering juggernaut that took the old world by storm. To commemorate their affect on modern society and technology, we discover just how innovative and ground-breaking this civilisation really was.

HEAD 2 HEAD
BIG ROMAN CITIES

Carthage
The centre of the defeated Carthaginian Empire, Rome made Carthage one of its main satellites with as many as 500,000 people.

Alexandria
The Egyptian city became prosperous in the Ptolemaic dynasty and by the time of Roman conquest had 500,000 to 750,000 inhabitants.

Rome
With an estimated population of 1 million and the home of the emperor, Rome was the empire's main urban metropolis.

DID YOU KNOW? *Lugo in Spain is now the only city in Europe to still be surrounded by intact Roman walls*

Engineering in Roman home life

The technology inside a Roman house

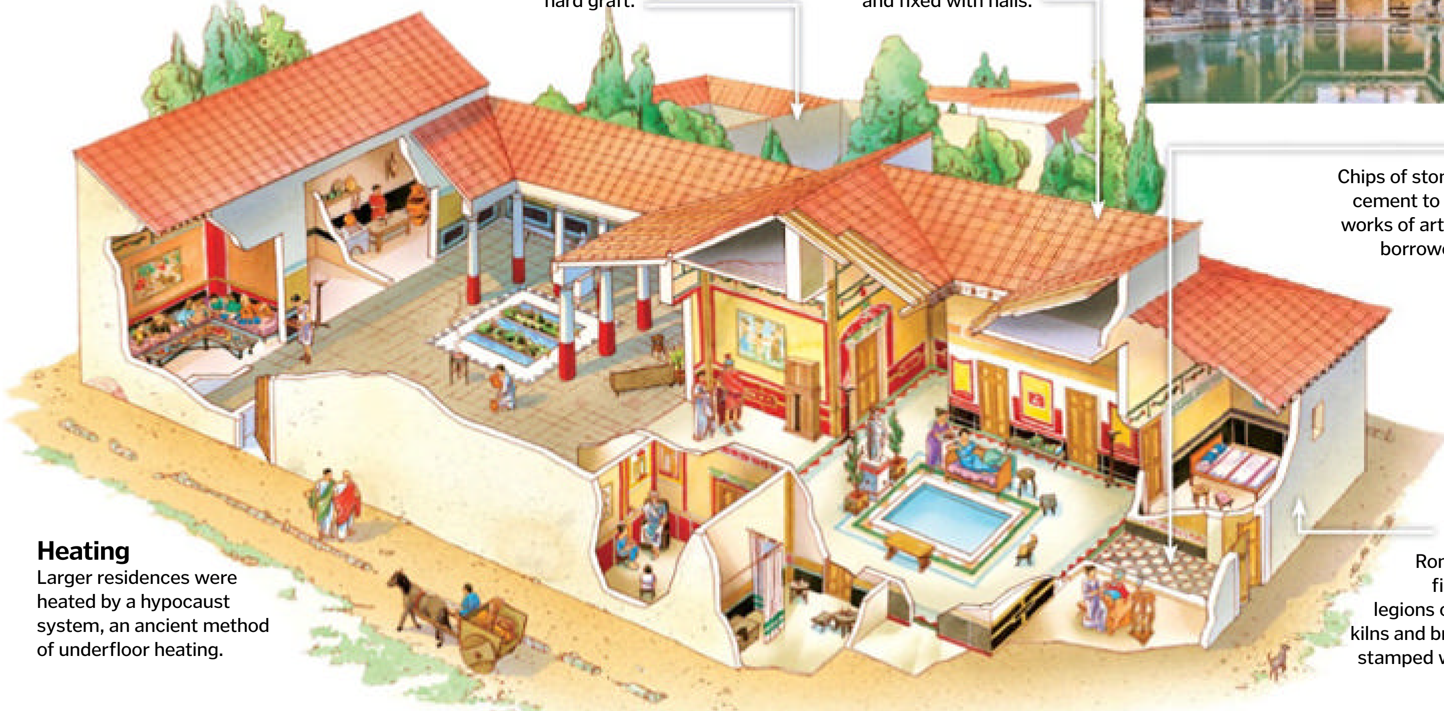
The citizens of Rome had to be properly housed to ensure that the vast urban sprawl could operate as an organised society. Prior to the Romans, impressive structures were built by the Egyptians and the Greeks but never on the scale of the Roman Empire with its extensive housing projects.

Roman building techniques owed a lot to Greek and Etruscan influences. Houses were one or two storeys high and included lots of different sections. Ideally adapted to the Mediterranean heat, the typical Roman house often had no windows (glass was rarely used), instead fitted with an atrium to act as an open-air courtyard in the middle of the building. Life in a house was boosted by a fully functioning public welfare system that provided grain to 300,000 of Rome's families every year. If you wanted some retail therapy, Trajan's Market had over one hundred tabernae (shops) selling a variety of goods.

Not every citizen was lucky or rich enough to own a house. Lower classes were put into one of Rome's many 'insulae' apartment buildings and there are believed to have been over 40,000 of these in the city. In fact, these apartments outnumbered family houses by 20 to one!

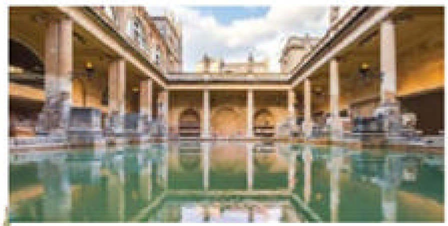
The Roman residence

More than just a roof above your head, the Roman house was quite complex



Building blocks
The Romans used pulleys and levers to shift large building blocks. Slaves carried out the hard graft.

Roof tiles
A stonesman would carve thin tiles from stone. These were laid on top of wooden beams and fixed with nails.

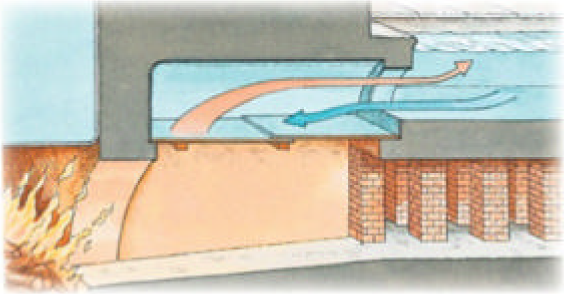


Mosaics
Chips of stone were laid into cement to create beautiful works of art. This technique borrowed from Greece.

Heating
Larger residences were heated by a hypocaust system, an ancient method of underfloor heating.

Clay bricks
Roman bricks were fired clay. Roman legions operated mobile kilns and bricks were often stamped with the mark of the legion.

Hypocaust heating system



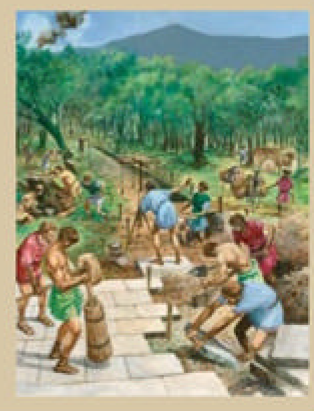
Convection currents
Underneath a raised floor, vents allowed heated air to travel freely and used convection currents to heat the tiles above. The warm air came from a wood-burning furnace.

Running the hypocaust
Slaves kept the system running by keeping the flame alight. It is still unknown how well the convection currents worked and whether some rooms got too hot because of the system.

Disadvantages
The hypocaust was reserved only for the wealthiest villas and large bathhouses. Also, the burning of wood produced toxic carbon monoxide fumes.

Roman roads

Roman roads interlinked cities and towns and allowed rapid military and administrative communications. Construction began with a trench, which was filled with a base of stones and rocks. These were packed together tightly, usually with cement, to create a firm foundation for armies to march on and chariots to ride across. Large paving stones were used on the surface. These were placed and fitted by hand along with channels on the side of the road that allowed water to run off into surrounding fields. In the UK, roads such as the A1 and A5 owe their origins to the Roman conquest of Britain.



Aqueduct engineering

How the Romans built their immense water-management network

Aqueducts weren't invented by Romans but were popularised by them. These structures were the life stream of a city. 1,300 drinking fountains and 144 public toilets were located in Rome and they were all fed by the complex system of aqueducts, which brought in fresh drinking water from rural areas. The system was accompanied by an elaborate network of sewers.

Rome's main sewer was known as Cloaca Maxima and carried dirty water out of the city and into the River Tiber. The first-ever aqueduct was the Aqua Appia, built in 312 BCE. It helped relieve the demand for water in a rapidly growing Rome. Where possible, the majority of an aqueduct was built underground to protect it from enemies. The iconic raised arches were only required when the structures neared a city or needed to cross a ravine.

The basic yet effective tools used in construction were the dioptra (measured angles) and chorobates (measured horizontal planes). These were handled by skilled army engineers who designed a gravity based system with dropshafts and chutes to help the water flow. This demonstrated excellent structural engineering and water management expertise and they were built so well that some are still operational to this day!

1 Building materials

Aqueducts were primarily constructed out of limestone that was mined from neighbouring quarries. These slabs of rock were bound together by Roman concrete and cement, which was made out of durable and waterproof volcanic sand called pozzolana.

2 Planning

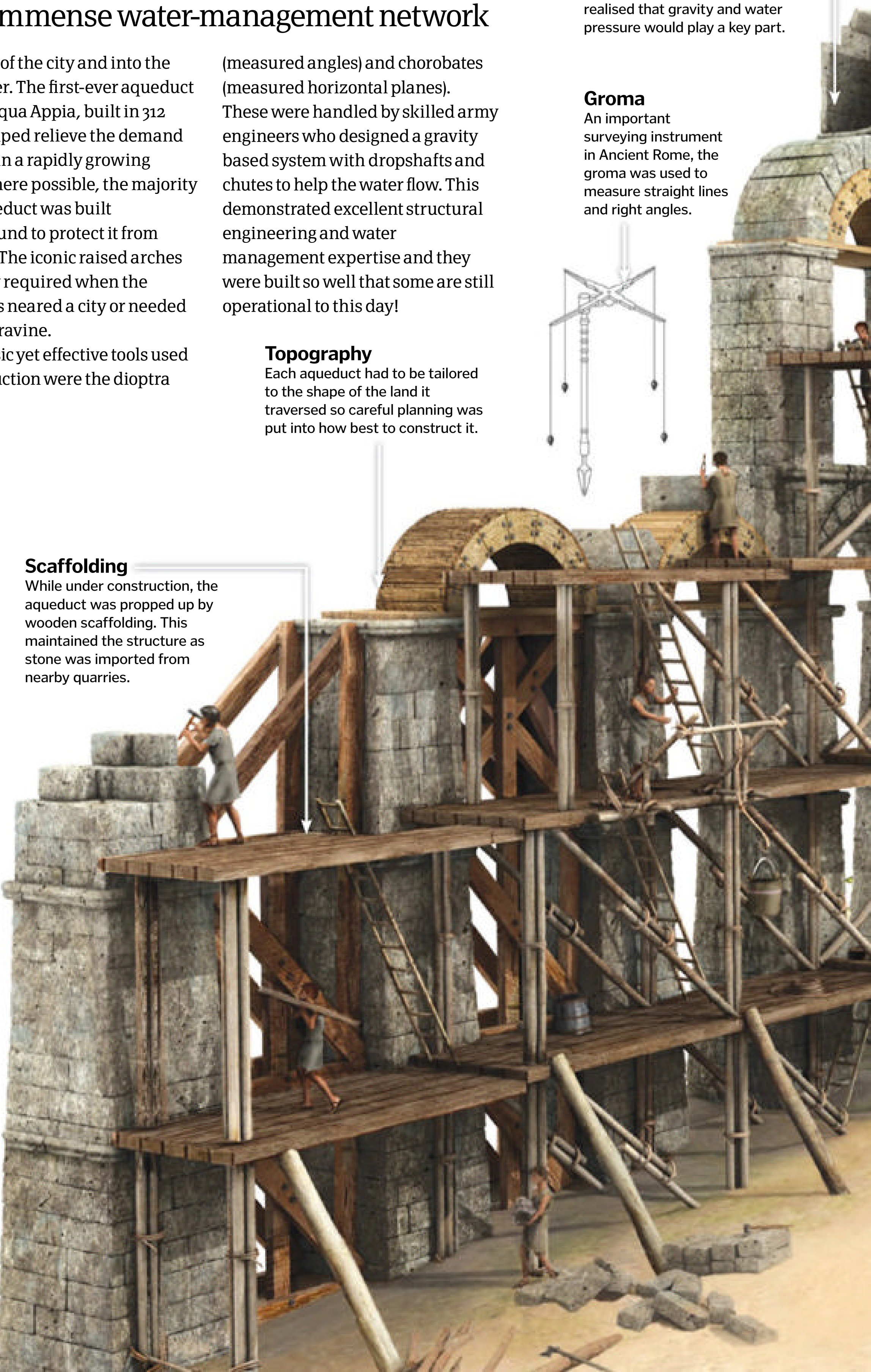
The building of aqueducts was often financed by the emperors themselves, so meticulous planning was put into the operation. The land needed to be surveyed by engineers to make sure it was fit for construction.

3 Construction techniques

The reinforced Roman concrete arch was an essential part of the aqueduct as it could hold the pressure and weight of the water after the wooden construction supports had been removed. Pulleys, wedges and screws were used as lifting apparatus.

4 Design and uses

The water was carried a great distance from spring to urban area and was then held in cisterns in the city and onto a network of pipes to each individual building. Aqueducts also aided a town's sewer system and protected against fires.



Hydraulics
Despite having a limited knowledge of construction science, the Roman builders realised that gravity and water pressure would play a key part.

Groma
An important surveying instrument in Ancient Rome, the groma was used to measure straight lines and right angles.

Topography
Each aqueduct had to be tailored to the shape of the land it traversed so careful planning was put into how best to construct it.

Scaffolding
While under construction, the aqueduct was propped up by wooden scaffolding. This maintained the structure as stone was imported from nearby quarries.

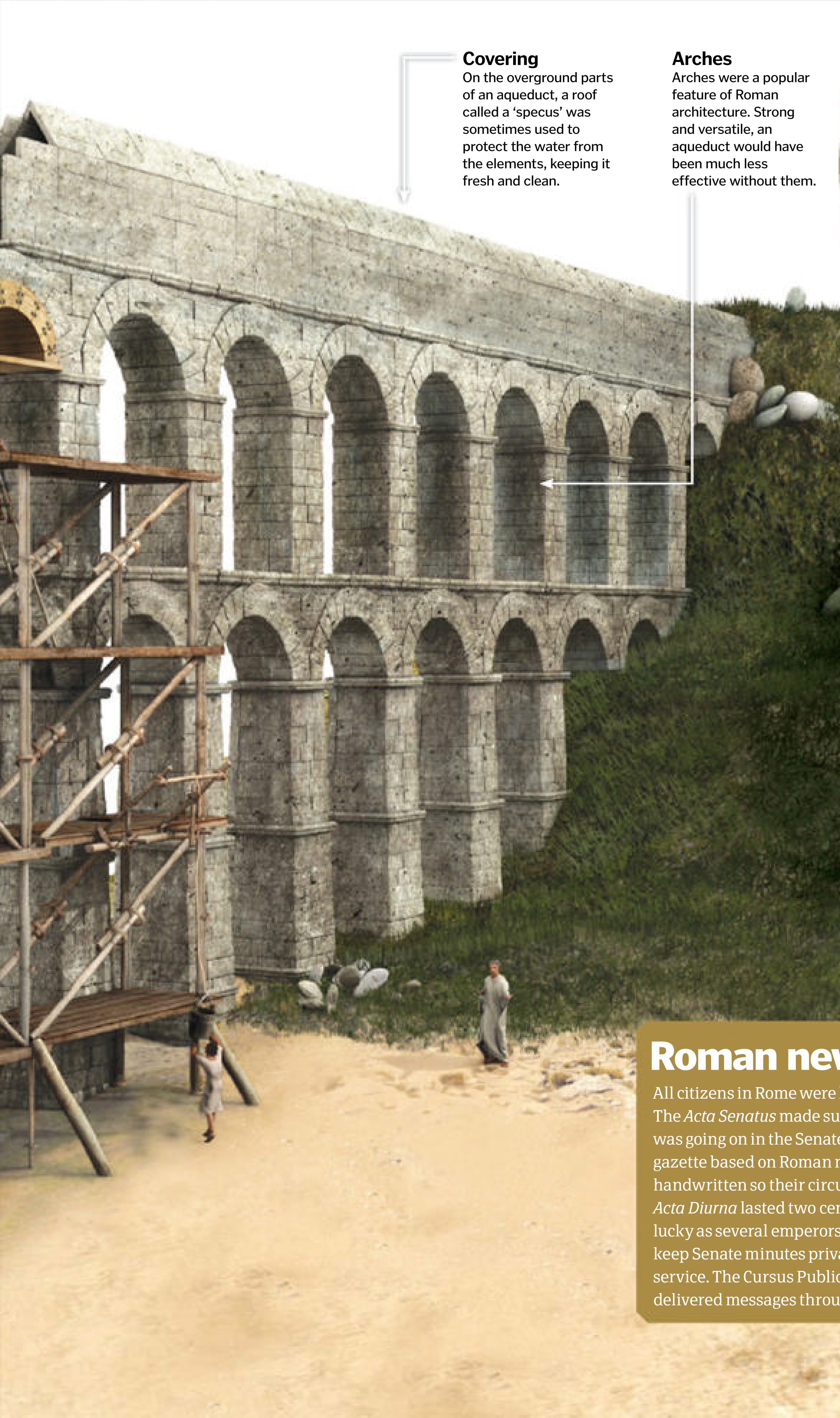
RECORD BREAKERS
CROWDED CAPITAL

1MILLION

ROME'S LONG-STANDING RECORD

Rome's population peaked at 1 million people when the empire was at the height of its powers. This number wasn't topped in Europe for nearly 2,000 years, until London began to prosper in the Industrial Revolution.

DID YOU KNOW? *Rome's aqueducts provided up to 1,000 litres (264 gallons) of water for every person in the city*



Covering
On the overground parts of an aqueduct, a roof called a 'specus' was sometimes used to protect the water from the elements, keeping it fresh and clean.

Arches
Arches were a popular feature of Roman architecture. Strong and versatile, an aqueduct would have been much less effective without them.

Flowing far

Many claim that aqueducts were one of the best Roman developments. Frequent throughout the Roman world, their effective and modern system was lost after the fall of the empire and never recovered until much, much later in human history. A lot of these structures were actually underground, but they are most fondly remembered for their overground segments with their iconic vaulted arches that were essential in their construction. As techniques improved, aqueducts were also used to supply out-of-town factories and mines with water. The longest aqueduct in Rome was the Aqua Marcia at 91 kilometres (57 miles) from source to city, but even longer systems were built across the empire.

Roman newspapers

All citizens in Rome were kept up-to-date with two daily newspapers. The *Acta Senatus* made sure the public was up to speed with what was going on in the Senate while the *Acta Diurna* was a daily gazette based on Roman news and weather. Both publications were handwritten so their circulation wasn't exceedingly high, but the *Acta Diurna* lasted two centuries of service. The *Senatus* wasn't so lucky as several emperors forbade its publication and preferred to keep Senate minutes private. They were also pioneers of the postal service. The Cursus Publicus was a state-run courier system that delivered messages throughout the Roman Empire.

Buildings

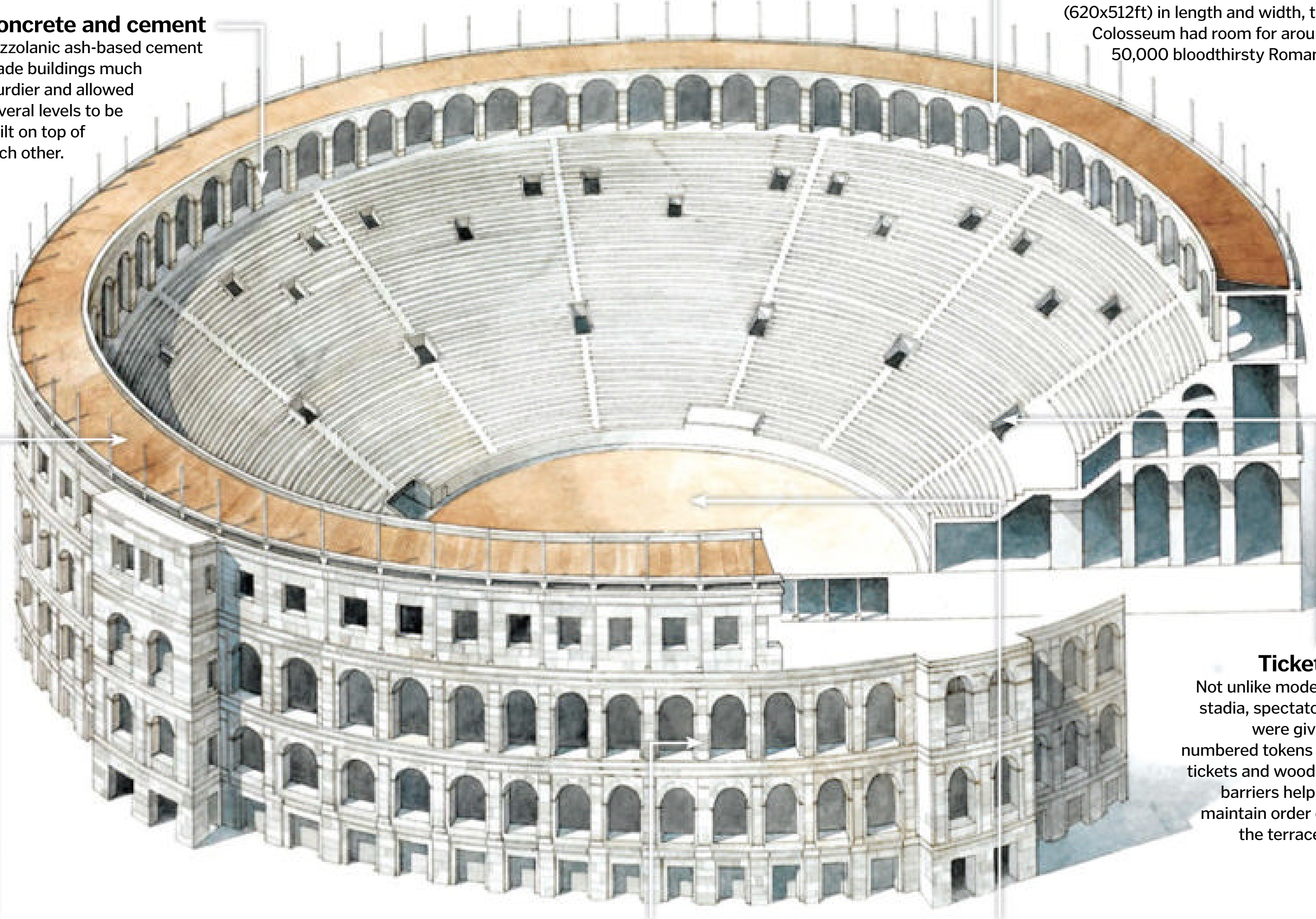
The biggest cities were home to the biggest buildings

In its prime Rome was one of the, if not the most, technologically advanced cities in the world. Containing huge, expansive buildings, revolutionary architecture and a housed, fed and watered population within its walls, the vast empire's capital in Rome was well ahead of its time.

The Colosseum became the cultural centre of Rome after its construction in 80 CE, but the capital also contained one of the largest sports stadiums of all time, the Circus Maximus, as well as other examples of stunning engineering, such as the Pantheon, the Arch of Septimius Severus and the Theatre of Pompey.

The Colosseum

How the centrepiece of the empire and its architecture was built



All in a name

The name 'Colosseum' comes from the word 'colossus' which was the name of giant statues erected in the city by Emperor Nero.

Concrete and cement

Pozzolanic ash-based cement made buildings much sturdier and allowed several levels to be built on top of each other.

Dimensions

48m (157ft) high and 189x156m (620x512ft) in length and width, the Colosseum had room for around 50,000 bloodthirsty Romans!

Tickets

Not unlike modern stadia, spectators were given numbered tokens as tickets and wooden barriers helped maintain order on the terraces.

Velarium

All the spectators in the Colosseum were protected from the hot Mediterranean sun by an awning called the velarium.

Construction

The Colosseum's outer wall was made from $100{,}000\text{m}^3$ (3.53mn ft^3) of limestone held together by 300 tons of iron clamps.

Arches

80 concrete arches meant the Colosseum had an extremely durable design, which has allowed it to stand for nearly 2,000 years!

Underground labyrinth

Underneath the Colosseum was a system of tunnels that elevated cages into the arena using a slave-run pulley system.

5 TOP FACTS
ROMAN MILITARY

Organisation
1 80 legionnaires were in a century. Together, six centuries made a cohort of 480 men. A legion had ten cohorts and the entire army contained 30 legions, a total of around 150,000 soldiers.

Training
2 Training lasted four months and consisted of marching, formation and weapons training. Recruits also learned to swim, ride a horse and use a bow and a sling.

Pay
3 A legionnaire would earn a basic 225 denarii for a year's service. Out of this wage packet were deductions for equipment, food and even a regiment savings bank.

Army oath
4 Each soldier would swear a 'sacrementum' when they began their service, pledging their allegiance to the emperor and vow never to abandon comrades or desert a battle.

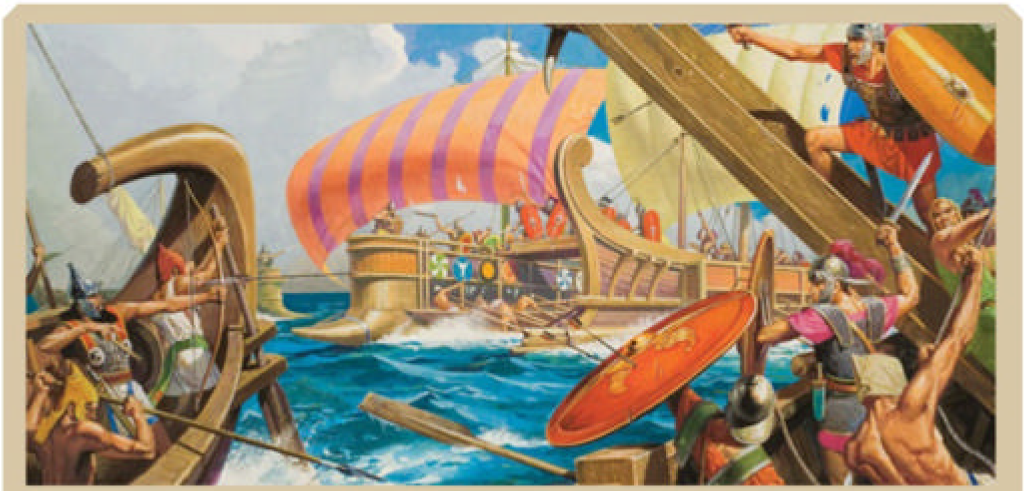
Clothing and armour
5 Armour was light but sturdy. The helmets and armour could repel projectiles while the military-issue tunic was comfortable enough to wear on long marches.

DID YOU KNOW? *Soldiers had to be able to march 32km (20mi) in five hours while carrying around 20.5kg (45lb) of equipment*

Military

Ingenious conquerors

On both land and sea, the Roman Empire dominated warfare for centuries, invading large portions of Europe and making significant inroads into Africa and Asia Minor. The Romans outwitted their opponents using expert battle tactics and perfectly engineered weapons and armour. Soldiers were divided into legions that served different territories and swore an oath of loyalty to the centurions. One of the main reasons why the Romans consistently beat their enemies (and what links them to today's military) is the fact that the army was a professional conscripted force. A full-time operation, a soldier was one of the highest-paid and most-respected occupations in the empire.



The war at sea

On the high seas of the Mediterranean, the Romans enjoyed even more dominance than on land. Using triremes and galleys propelled by teams of over 100 men, ships attacked either by ramming the opposition or boarding their ships. Owing a lot of their strategies to reverse-engineering methods learnt from the Greeks and Carthaginians, maritime superiority was essential for victory in the Punic Wars and Egypt campaigns. The senior arm of the Roman navy was known as the Classis Misenensis and except for internal civil wars, achieved total marine dominance for Rome after the Punic Wars.

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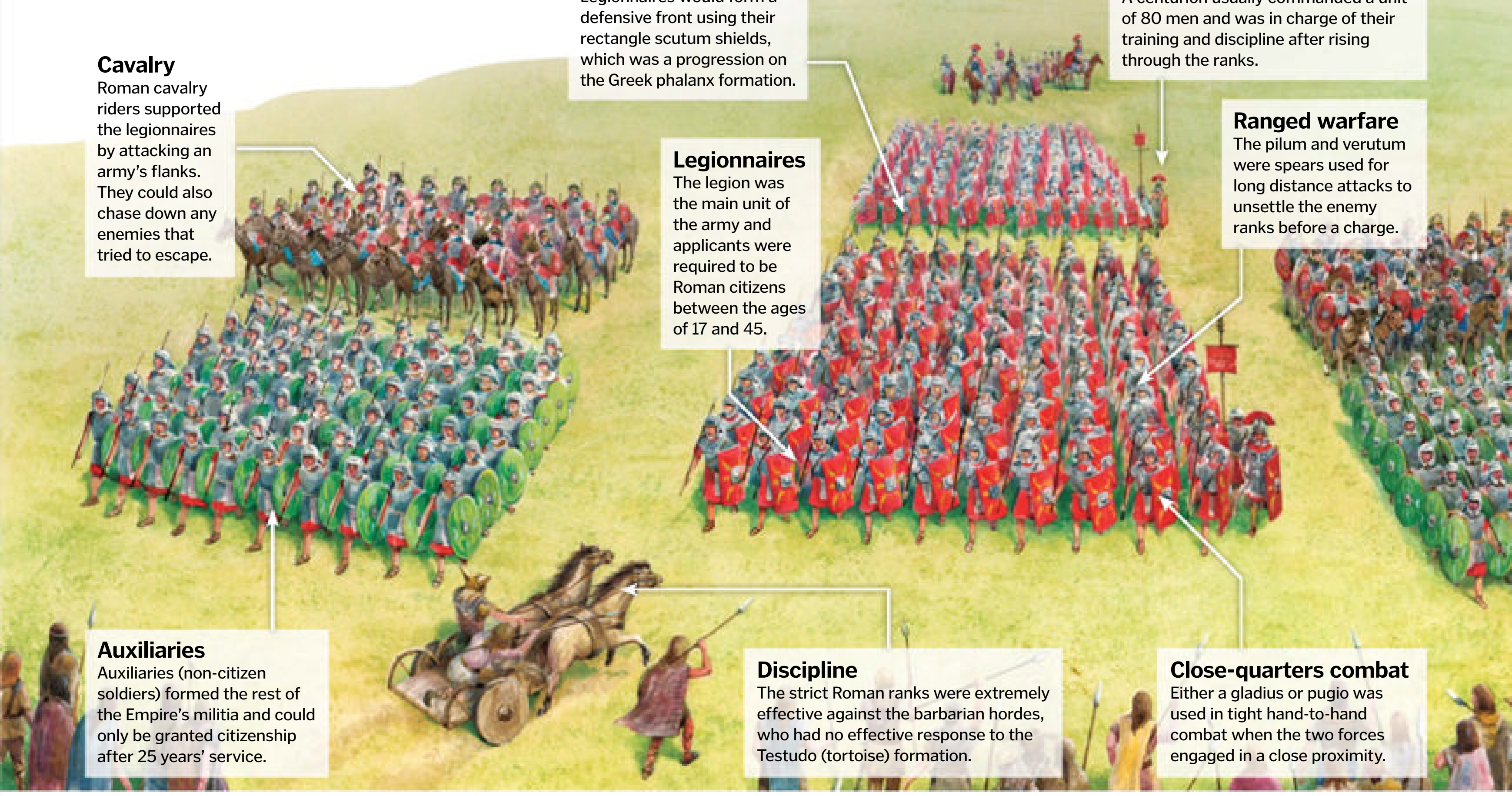
Romans on the battlefield

What a battle between the Empire and a barbarian horde would have looked like



Cavalry
Roman cavalry riders supported the legionnaires by attacking an army's flanks. They could also chase down any enemies that tried to escape.

Formation
Legionnaires would form a defensive front using their rectangle scutum shields, which was a progression on the Greek phalanx formation.

Legionnaires
The legion was the main unit of the army and applicants were required to be Roman citizens between the ages of 17 and 45.

Centurions
A centurion usually commanded a unit of 80 men and was in charge of their training and discipline after rising through the ranks.

Ranged warfare
The pilum and verutum were spears used for long distance attacks to unsettle the enemy ranks before a charge.

Auxiliaries
Auxiliaries (non-citizen soldiers) formed the rest of the Empire's militia and could only be granted citizenship after 25 years' service.

Discipline
The strict Roman ranks were extremely effective against the barbarian hordes, who had no effective response to the Testudo (tortoise) formation.

Close-quarters combat
Either a gladius or pugio was used in tight hand-to-hand combat when the two forces engaged in a close proximity.

The Circus Maximus

Explore the largest stadium in the history of the Roman world and find out what spectacular events were held there

As the name suggests, the Circus Maximus was Rome's biggest circus, or racetrack. It was established by Tarquinius Priscus, the fifth king of Rome, in the sixth century BCE. The first circus to be erected in the city, the original building was a wholly wooden construction. Increased in size by Julius Caesar, a triple stone arch was later added to honour Emperor Titus, before the entire structure was rebuilt in stone and concrete by Emperor Trajan in 103 CE, after a fire destroyed its wooden predecessor.

Although various monumental additions were continually added during the following centuries, the Circus Maximus essentially remained the same for the next 400 years. Despite the massive cost of the circus's construction and the popularity of chariot racing, admission was entirely free – anyone could attend races, including poorer citizens.

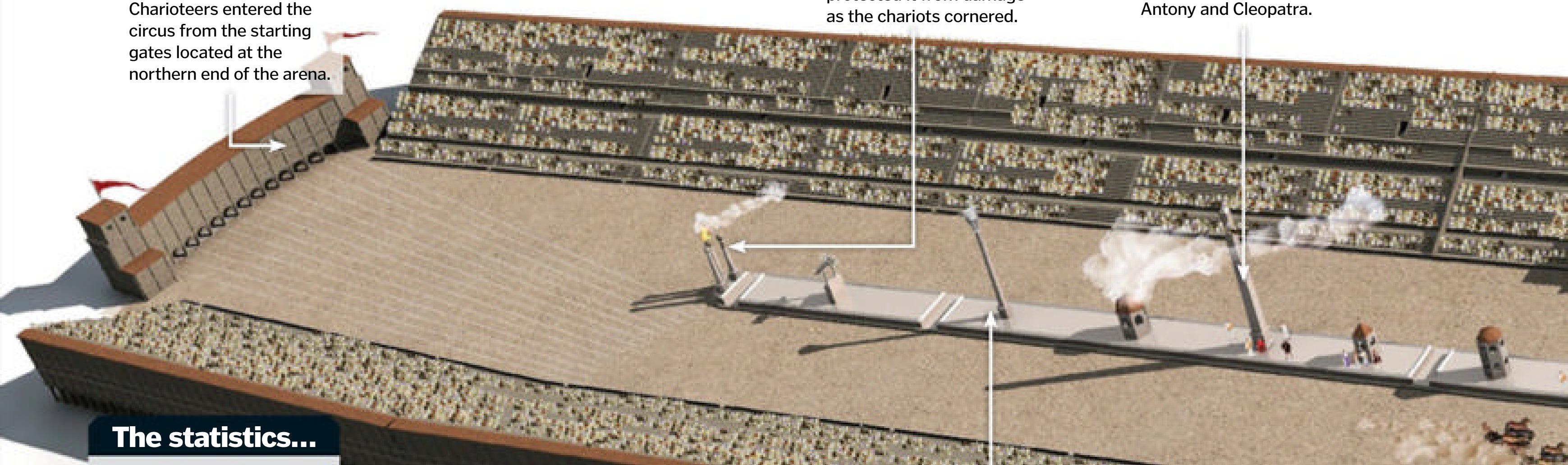
Betting was popular with all classes and under the stands were food stalls, stables and shops that serviced charioteers and public alike. Several small temples and shrines were also incorporated into the complex and religious festivals were held annually within its walls. Other forms of entertainment also featured in the venue's yearly calendar, including musical recitals, athletics competitions, plays and staged animal hunts.

With the advent of Christianity and the crumbling Roman Empire, the fortunes of the Circus Maximus quickly declined. The last recorded chariot race took place in 549 CE, after which Rome's greatest entertainment venue was abandoned and became a quarry.

In 1587, the two Egyptian obelisks that stood on the central spine were removed by Pope Sixtus V to adorn different parts of the city; the rest of the building disappeared soon after. Today, the circus's site is used as a public park and there is little to indicate its former glory.

A trip to the Roman circus

How was the Circus Maximus laid out to enable vast crowds to comfortably enjoy sport and other spectator events?



Starting gates
Charioteers entered the circus from the starting gates located at the northern end of the arena.

Metae
Made from three conical stone pillars, these turning posts marked the ends of the central dividing barrier and protected it from damage as the chariots cornered.

Egyptian obelisk
Removed from Heliopolis in Egypt by Augustus, the obelisk commemorated the Roman victory over Antony and Cleopatra.

Spina
Running down the length of the circus, chariots raced around this central brick and stone barrier.

Seating
Rising some three storeys or more in height, the seating in the Circus Maximus was built of stone and brick, with wooden sections added at the top.

The statistics...

Circus Maximus

Length: 621m (2,037ft)
Width: 118m (387ft)
Height: Up to 30m (98ft)
Area: 84,000m^2 (904,200ft^2)
Seating capacity: 250,000

HEAD2HEAD

ROMAN STADIA

1. BIG

Stadium of Philippopolis

Built near Plovdiv, Bulgaria, in the second century CE, this stadium is 240m (787ft) long and could host 30,000 people.

2. BIGGER

Constantinople Hippodrome

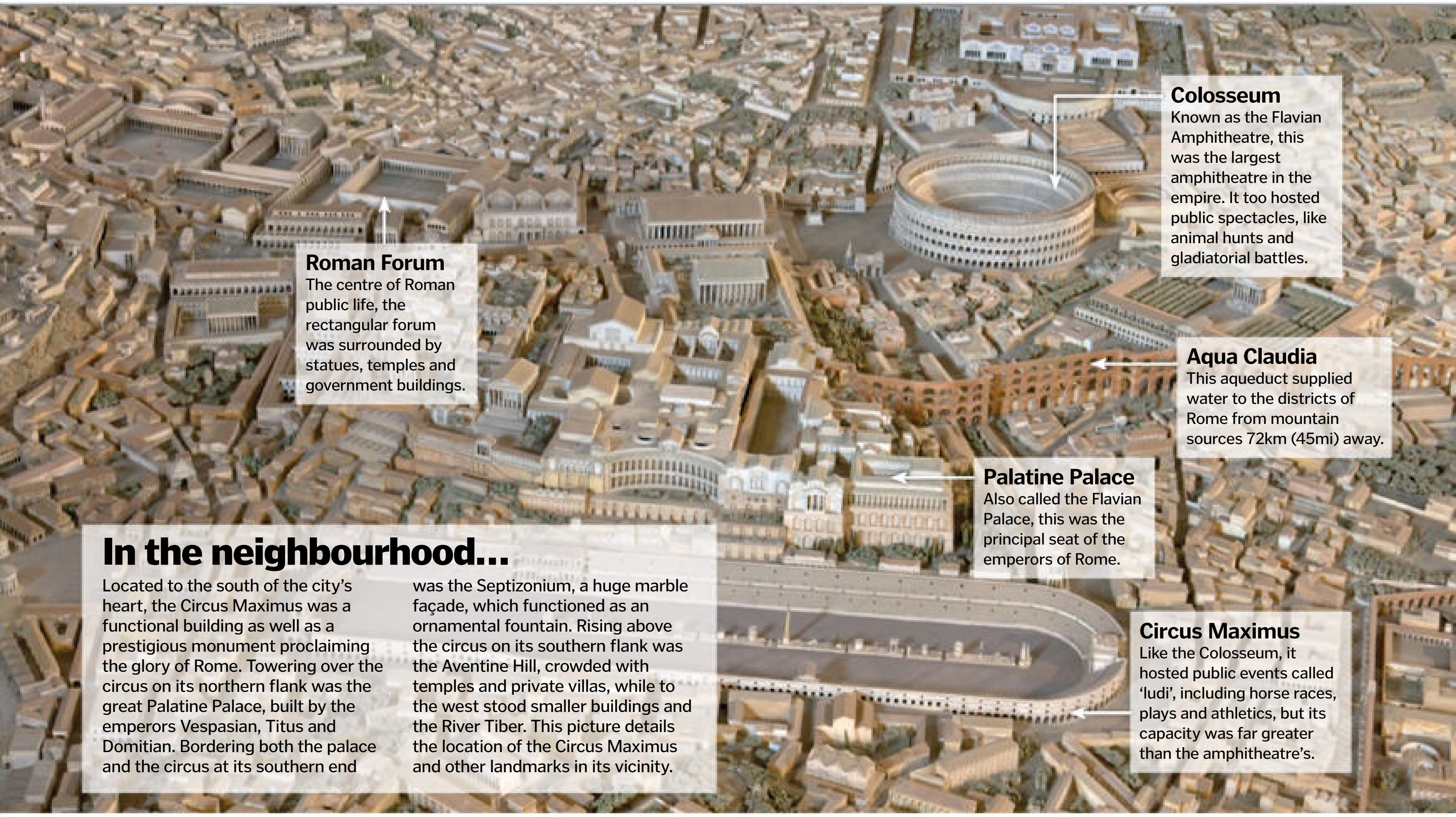
450m (1,476ft) in length, the Hippodrome built next to the Great Palace in Constantinople could seat 100,000 spectators.

3. BIGGEST

Circus Maximus

At 621m (2,037) long and with a 250,000 capacity (according to Pliny), this great Roman circus was never surpassed.

DID YOU KNOW? *The celebration for Italy's World Cup 2006 victory was held on the site of the Circus Maximus*



Colosseum
Known as the Flavian Amphitheatre, this was the largest amphitheatre in the empire. It too hosted public spectacles, like animal hunts and gladiatorial battles.

Roman Forum
The centre of Roman public life, the rectangular forum was surrounded by statues, temples and government buildings.

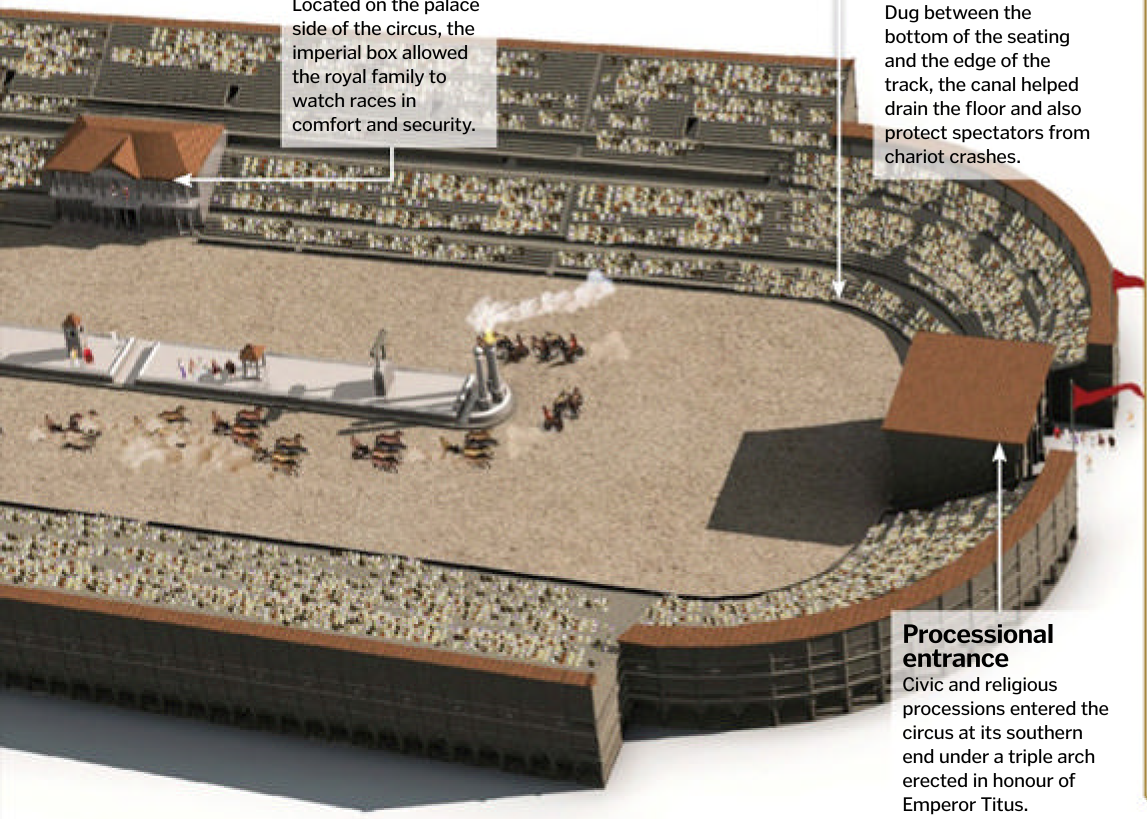
Aqua Claudia
This aqueduct supplied water to the districts of Rome from mountain sources 72km (45mi) away.

Palatine Palace
Also called the Flavian Palace, this was the principal seat of the emperors of Rome.

Circus Maximus
Like the Colosseum, it hosted public events called 'ludi', including horse races, plays and athletics, but its capacity was far greater than the amphitheatre's.

In the neighbourhood…

Located to the south of the city's heart, the Circus Maximus was a functional building as well as a prestigious monument proclaiming the glory of Rome. Towering over the circus on its northern flank was the great Palatine Palace, built by the emperors Vespasian, Titus and Domitian. Bordering both the palace and the circus at its southern end was the Septizonium, a huge marble façade, which functioned as an ornamental fountain. Rising above the circus on its southern flank was the Aventine Hill, crowded with temples and private villas, while to the west stood smaller buildings and the River Tiber. This picture details the location of the Circus Maximus and other landmarks in its vicinity.



Imperial box
Located on the palace side of the circus, the imperial box allowed the royal family to watch races in comfort and security.

Drainage canal
Dug between the bottom of the seating and the edge of the track, the canal helped drain the floor and also protect spectators from chariot crashes.

Processional entrance
Civic and religious processions entered the circus at its southern end under a triple arch erected in honour of Emperor Titus.

Chariot racing in Roman times

Chariot racing was probably the Roman world's equivalent of football. Inherited from the Ancient Greeks and Etruscans, the sport was refined by the Romans and practised throughout the empire. Dangerous to horses and charioteers alike, there were frequent accidents and even deaths during races in the circus.

There could be as many as 24 chariot races in a circus per day and although there were basic rules for behaviour while racing, charioteers often deliberately crashed into opponents or tried to force them into the central barrier.

An average race in the Circus Maximus would see up to 12 teams of charioteers lined up against each other, each chariot drawn by four horses competing over a distance of 6.4 kilometres (four miles). There were four principal teams – the Reds, Whites, Greens and Blues – the latter two of which rose to great prominence.

Fans followed their team's progress closely, much like football clubs do today. Fierce rivalry often resulted in violence between factions and sometimes even riots.

A highly paid sport, the most famous Roman charioteer, Gaius Appuleius Diocles, won 1,462 out of his 4,257 races. When he retired at the age of 42, he had amassed winnings of 35,863,120 sesterces – approximately £9 billion ($15 billion) in today's money – making him the highest-paid sports star in history.

© SPL; Alamy

The tomb of a 2,400-year-old mummy known as the Siberian Ice Maiden
Inset: One of three Incan children excavated on the summit of Cerro Llullaillaco, Argentina

History of ice mummies

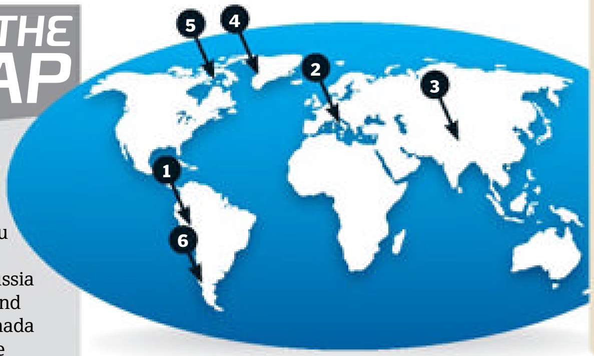
Preserved in ice for centuries, even millennia, how did these people freeze?

On an early autumn afternoon in 1991, Erika and Helmut Simon were walking off the beaten track in the Alps when they encountered a corpse protruding from the ice of a retreating glacier. It looked so fresh that they assumed it was the body of an unfortunate skier or climber – but this was Ötzi, an early-Bronze Age hunter who roamed the area 5,300 years ago. As valuable an archaeological find as he was though, Ötzi is far from a unique specimen.

Ancient corpses interred in ice have been found across the globe, whether they were the victim of arbitrary violence, an accident or, in a more recent and famous case, a ritual sacrifice. The ice mummy Juanita was found in 1995 on top of Mount Ampato, Peru, having been sacrificed to Incan gods at the age of only 12-14 at some point in the 16th century.

The sub-zero conditions would have preserved their bodies indefinitely. But after removing them from the ice, the museums in which they're housed need to keep their humidity high (around 90 per cent) and temperature below -6 degrees Celsius (21.2 degrees Fahrenheit) to make sure that they do not deteriorate.

ON THE MAP



Ice mummy sites around the world

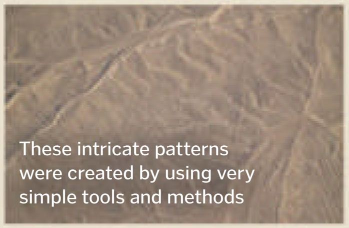
1 Mount Ampato, Peru
2 The Alps, Italy
3 Altai Mountains, Russia
4 Qilakitsoq, Greenland
5 Beechey Island, Canada
6 El Plomo Peak, Chile

What are the Nazca lines?

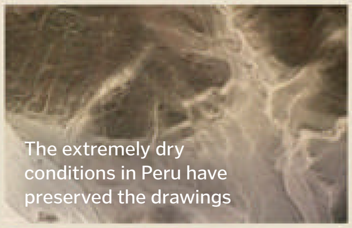
Ancient drawings cover the Peruvian plains, but where did they come from?

The Peruvian coastal plain in South America is home to a wonder of archaeology. The ground is scarred by images, or geoglyphs, known as the Nazca lines, thought to have been constructed by the people of Nazca between 500 BCE and 500 CE.

The ancient artworks – most easily viewed from the air – were created by methodically removing dark-coloured gravel from the surface to reveal lighter material below. The plains' unique climate has preserved the lines for thousands of years. Each year, the region receives just 20 minutes of rainfall on average, and the ground is mostly stone and gravel, which prevents the striking images from eroding in the wind.



These intricate patterns were created by using very simple tools and methods



The extremely dry conditions in Peru have preserved the drawings

The complexity of the Nazca lines has led to some wild theories as to their origin

Going on a Nazca safari...

Dog
This 51m (167ft) canine is thought to be an image of an ancestor of the hairless Peruvian dog. It was kept by the Nazca as a pet, used as a watchdog.

Spider
An impressive 45m (150ft) in length, this Nazca arachnid was one of the very first figures to be studied in the region by scientists back in the Thirties.

Hummingbird
The Nazca hummingbird measures 97m (318ft) from beak to tail. Carved on a raised plateau, it is one of the most prominent of the animals.

© Thinkstock; Corbis; Getty; Martin St Amant

Making the Terracotta Army

Meet the immortal warriors built to defend the Chinese Emperor Qin Shi Huang and find out how they were constructed over 2,200 years ago

The Terracotta Army comprises a huge collection of sculptures found within the mausoleum of the first emperor of China, Qin Shi Huang. Featuring close to 9,000 figures, objects and weapons, the massive earthenware cohort was built to accompany Emperor Qin into the afterlife.

The terracotta army was manufactured by thousands of labourers and craftsmen during Qin's reign around 220-210 BCE. The material used to build the sculptures was harvested from the site of the mausoleum – Mount Li in Shaanxi Province. According to detailed examination of the figures, their heads, arms, legs and torsos were modelled and fired separately, only being assembled afterwards, so many more were probably made but damaged during production.

While today the excavated figures have reverted to their natural orange-red colour due to exposure to the air, when originally completed these sculptures would have been brightly painted and highly detailed – evidence of which can still be found on a few well-preserved specimens. What does remain unchanged is their original layout, with the thousands of statues arranged in accurate military formations, with generals and other important officers identified.

The Terracotta Army is but one feature – albeit the most impressive one to date – of Qin's larger mausoleum and necropolis, with the emperor's tomb and underground palace yet to be excavated. According to famous Chinese historian Sima Qian (circa 145-90 BCE), all manner of treasures are concealed there, but the site is considered sacred so there are no immediate plans to disturb the tomb.

Beyond the warriors…

Officials

Qin also needed protection from the trials and tribulations of administration work. Terracotta court officials and counsellors can therefore be found throughout his enormous mausoleum.

Acrobats

In contrast to the sombre and serious terracotta soldiers, other pits within Qin's mausoleum have revealed acrobats and dancers, each crafted in animated positions and with strong facial expressions.

Musicians

Music was important in Ancient China, which is represented by the abundance of musicians and instruments. A set of Bianzhong bronze chimes was recently unearthed in very good condition.

Animals

Emperor Qin Shi Huang was clearly a big fan of animals, as a host of sacred creatures, such as cranes and swans, as well as a full-blown imperial zoo, have been found inside the mausoleum.

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All about Qin

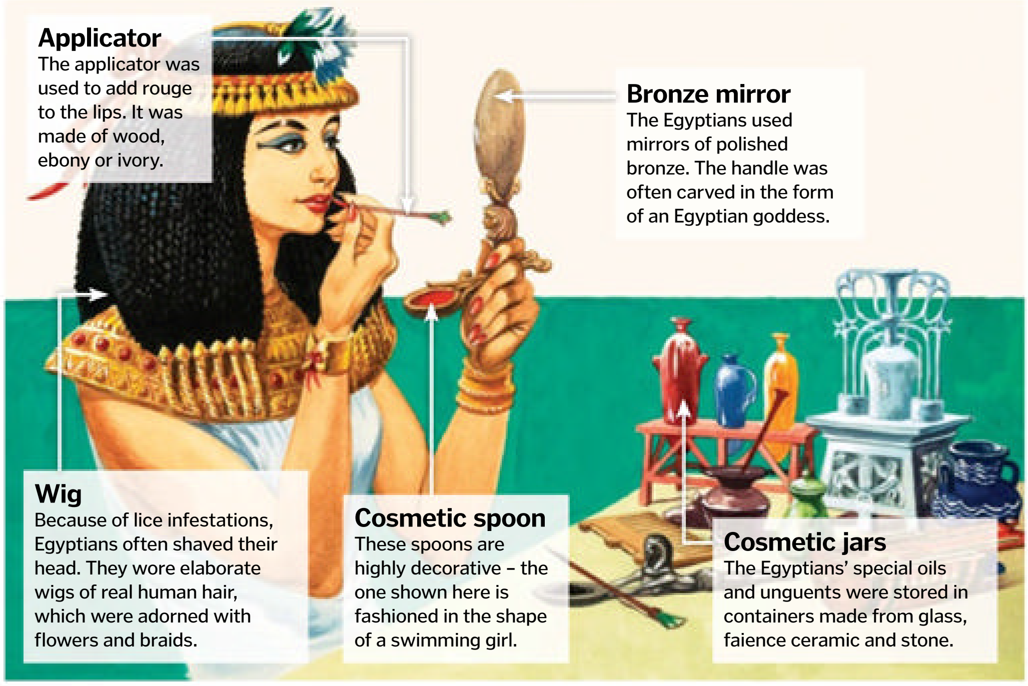
Qin Shi Huang, the legendary first emperor of China, brought the Warring States period to a close in 221 BCE. His reign was typified by military conquest, with campaigns into modern China's southern lands, as well as massive public projects; examples include the unification of state walls into the Great Wall of China and a national road system. Qin ruled unopposed until his death in 210 BCE – an event he reportedly attempted to avoid by undertaking a search for a fabled elixir of immortality.

Ancient Egyptian cosmetics

Makeup was once an important part of everyday life in Egypt – find out why

In Ancient Egypt, the image of an individual often acted as a substitute for the body in the afterlife. Therefore, in funerary paintings, both males and females are shown in their best clothes, wigs and makeup.

In life, the Egyptians utilised a variety of pigments to adorn the face. The most predominant of these was kohl, which was used to line the eyes. Kohl came from two sources: a green eye paint made of mineral malachite and a black liner derived from galena, a form of lead ore. Women used red ochre to form a light blush for cheeks and lips, while henna was used to paint the nails and dye the hair. Cosmetics were also applied for practical reasons – the military wore it to protect their eyes from the intense glare of the African Sun. Moreover, it had a religious resonance – each day, in the holy sanctuary of the temple, the god was anointed with makeup as a symbol of celestial regeneration.



Applicator
The applicator was used to add rouge to the lips. It was made of wood, ebony or ivory.

Bronze mirror
The Egyptians used mirrors of polished bronze. The handle was often carved in the form of an Egyptian goddess.

Wig
Because of lice infestations, Egyptians often shaved their head. They wore elaborate wigs of real human hair, which were adorned with flowers and braids.

Cosmetic spoon
These spoons are highly decorative – the one shown here is fashioned in the shape of a swimming girl.

Cosmetic jars
The Egyptians' special oils and unguents were stored in containers made from glass, faience ceramic and stone.

Origins of chocolate

Why it was more than just a tasty snack…

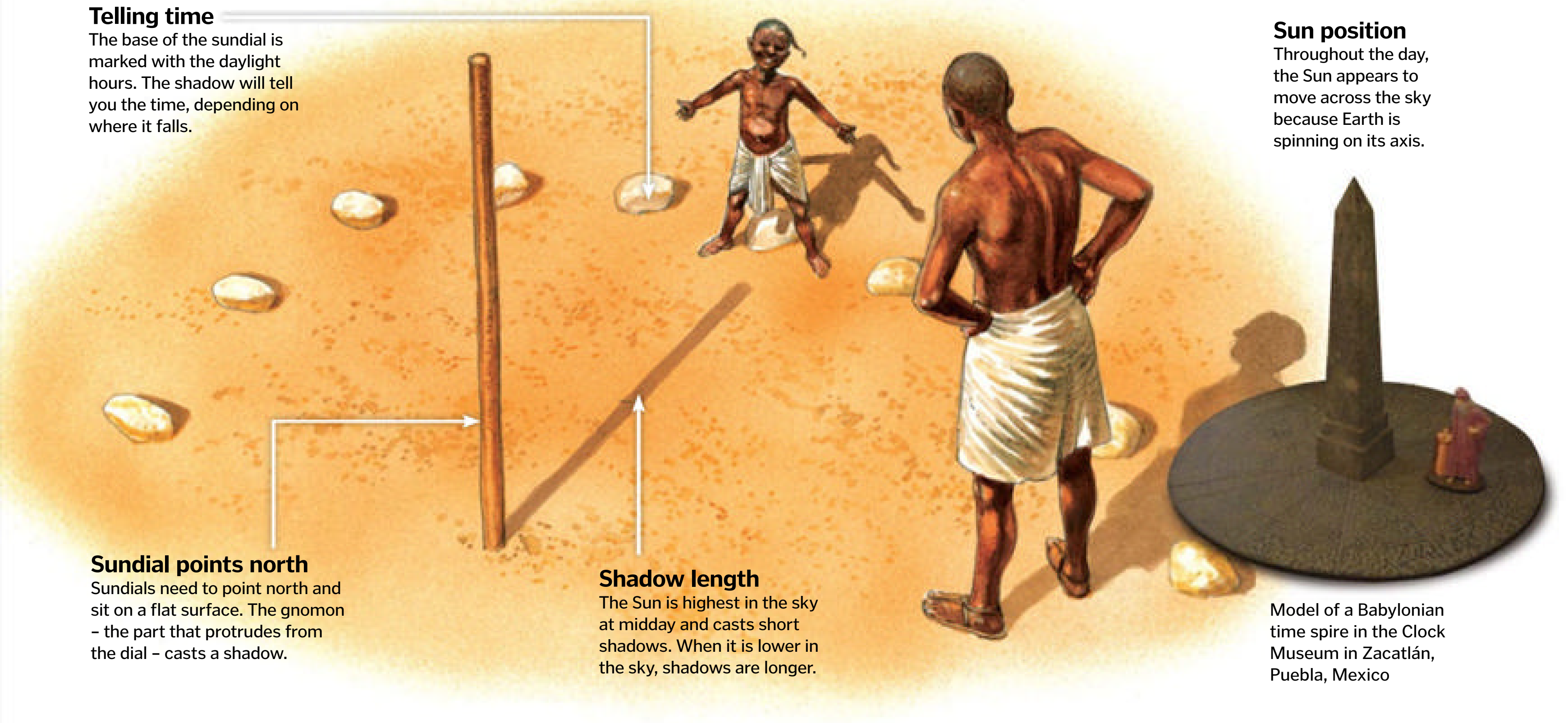
Chocolate is derived from the theobroma ('food of the gods') cacao tree and was consumed by the Mayans as a drink. Chocolate became a sacred elixir to both the Mayans and Aztecs; it was used during state executions and religious ceremonies. Archaeologists have discovered residues of chocolate in ancient jars that were found in Honduras and dated to 1100 BCE. Cocoa trees grew in abundance throughout the Mayan territories, and by 600 CE their pods (pictured) were processed in order to produce a frothy, bitter drink. The Mayans blended their chocolate with spices like chilli pepper and vanilla; once consumed they were believed to ward off tiredness. Evidence suggests that cocoa beans were also ground to a powder. During this process, other ingredients could be added – in this instance, the resulting powder was mixed with cold water to create porridge.

© Look and Learn; Corbis

How sundials tell the time

Discover how this ancient contraption worked

The sundial is one of the world's oldest scientific instruments. Designed to tell the time to the nearest hour, the ancient contraption was first created by the Babylonian and Egyptian civilisations and works by measuring the Sun's movement across the sky. The mechanism's dial is known as a gnomon or style and contains numerals representing the hours of the day, so when a shadow (or shard of light in some variations) is present on a specific number, that is the current hour. Sundials vary by their latitude. The Sun appears to take various paths across the sky in different parts of the world so a sundial must be tailored for the location it is in. Also, the time shown can vary by how close it is to a time-zone boundary. Clearly, they work better in sunnier areas, so they are more effective in the Mediterranean than in England!



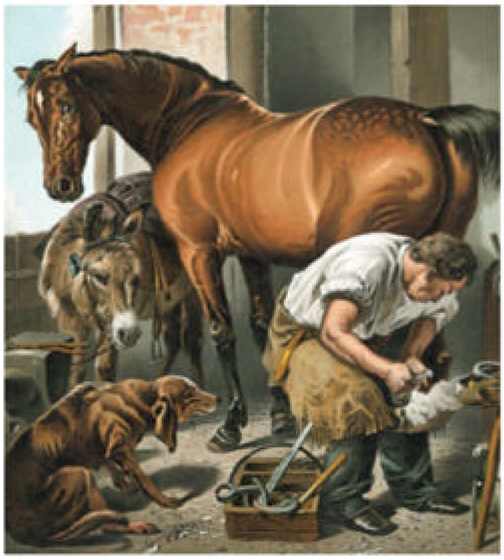
Telling time
The base of the sundial is marked with the daylight hours. The shadow will tell you the time, depending on where it falls.

Sun position
Throughout the day, the Sun appears to move across the sky because Earth is spinning on its axis.

Sundial points north
Sundials need to point north and sit on a flat surface. The gnomon – the part that protrudes from the dial – casts a shadow.

Shadow length
The Sun is highest in the sky at midday and casts short shadows. When it is lower in the sky, shadows are longer.

Model of a Babylonian time spire in the Clock Museum in Zacatlán, Puebla, Mexico



© Look and Learn, Dreamstime

Horse shoeing

Why do horses wear shoes and how are they fitted?

Ever since horses were first domesticated thousands of years ago, horsemen realised the importance of protecting their animals' feet. On hard or rocky terrain, shoes protected a horse's hooves from cracking or wearing down faster than they could grow. In soft, wet terrain – like the farmlands of northern Europe – shoes stopped their hooves from becoming porous and unstable, as well as helping the horse gain a good footing.

To prepare the foot, a farrier – an expert who shoes horses for a living – gives the horse a basic manicure by levelling off the hoof with a rasp and trimming excess growth. Next, they take a shoe made steel or aluminium and heat it in a forge until it glows red-hot. The shoe is quickly placed against the hoof to makes an impression, which the farrier uses as a guide for reshaping the malleable metal with a hammer and anvil. The shoe is cooled in water and fixed to the hoof with nails, which are angled so they exit the outer wall of the hoof and can be bent down to form clenches. Finally, the edges are smoothed down with a rasp.

The art of mummification

Mummies have been found in many parts of the world, but Egyptian mummies are the most well-known due to their distinctive appearance and unique embalming process

Ancient Egyptians used to bury their dead directly in the hot sand, which dried and preserved them somewhat. When they began using caskets, the bodies decayed instead. Around 2600 BCE, Egyptians began experimenting with a way to preserve their ancestors. They learned that bodies decayed from the inside out, starting with their organs. Embalmers perfected a process by which the organs were removed and the body dried prior to burial. This practice, known as mummification, was used for nearly 3,000 years.

Mummification was an expensive process and could take up to 70 days to complete. The embalmers worked in open tents, out in the desert and away from the general population. After washing the body, they removed the brain from the skull. In order to get into the brain cavity, embalmers put a chisel up the body's nose and hit it with a hammer to crack through the bone. Then, they inserted a long hook to pull out brain matter.

After cutting a slit in the left side of the body, embalmers removed the abdominal organs. They were washed, wrapped in linen and packed in jars. Natron, a naturally occurring salt, was added as a drying agent. The body was rinsed with wine and filled with incense and natron, then covered with more natron. A slanted table allowed fluids to drip from the body as it dried while guards kept away scavengers. Once the body was dry, embalmers wrapped it in linen strips in several stages and coated it with resin. The linen helped keep the body together and prevented moisture from entering. A rigid scaffold was then fitted over the body and a funeral mask attached to the face. Finally, the completed mummy was placed into a container decorated to look like a person, called a suhet.

An extreme way of wrapping up warm for winter

© Thinkstock

> "The practice of mummification was used for nearly 3,000 years"

© 2005 David Monniaux

Britain's tribal territories

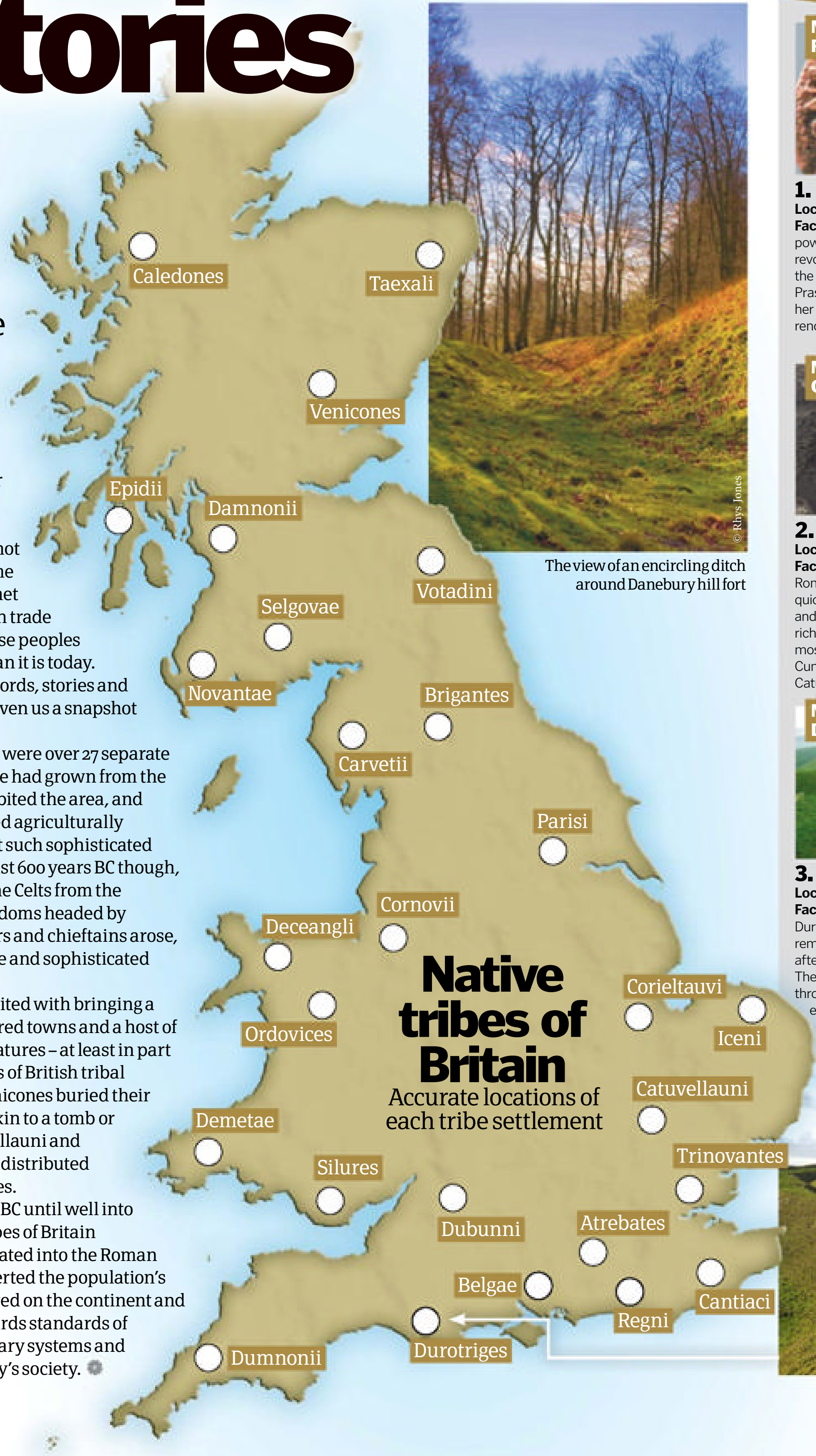
Before the Roman invasion in 55 BC, Britain was characterised by a large number of ancient tribes, each with its own culture

While the first modern humans populated the area we now call Britain at the end of the Ice Age (6,500 BC), very little is known about the intricacies of their culture and peoples until recorded history begins circa the Roman invasion of 55 BC. Indeed, if it were not for the Roman chroniclers of the time such as Tacitus and Ptolemy, who met the ancient tribes of Britain either in trade or in war, our sketchy picture of these peoples would be even more incomplete than it is today. However, centuries of historical records, stories and archaeological finds have at least given us a snapshot of their lives, leaders and customs.

Before the Roman invasion there were over 27 separate tribes living in Britain. These people had grown from the early hunter-gathers who had inhabited the area, and later the farmers who had developed agriculturally focused societies and who had built such sophisticated structures as Stonehenge. For the last 600 years BC though, influenced much by the arrival of the Celts from the continent, expansionist tribal kingdoms headed by dynastic and highly territorial rulers and chieftains arose, delivering cultures of fierce violence and sophisticated manufacture, artistry and trade.

While the Romans are often credited with bringing a unified currency, as well as structured towns and a host of amenities and technology, these features – at least in part – were already integrated into areas of British tribal society. Some tribes such as the Venicones buried their dead in stone casings, very much akin to a tomb or coffin. Others, like the Iceni, Catuvellauni and Atrebates, had already created and distributed currency throughout their territories.

Over 200 years, however, from 55 BC until well into the 2nd Century AD, the ancient tribes of Britain were either conquered or indoctrinated into the Roman empire, a process that largely converted the population's attitudes and cultures to those shared on the continent and saw a gradual climb in society towards standards of administration, architecture, sanitary systems and health care that resonate with today's society.



Native tribes of Britain

Accurate locations of each tribe settlement

© Rhys Jones

The view of an encircling ditch around Danebury hill fort

Head to Head

ANCIENT BRITISH TRIBES

© PHG.COM

MOST REBELLIOUS

1. Iceni

Located: Norfolk

Facts: One of the most rich and powerful tribes in Britain, the Iceni revolted against the Romans after the death of their client-king Prasutagus and were lead until her death by Prasutagus' wife, the renowned Queen Boudicca.

© John Opie

MOST CIVILISED

2. Catuvellauni

Located: South-east

Facts: One of the most pro-Roman tribes, the Catuvellauni quickly adopted Roman lifestyles and, as a result, were made very rich and powerful. One of the most famous British tribal kings, Cunobelinus, heralded from the Catuvellauni.

© Nigel Mykura

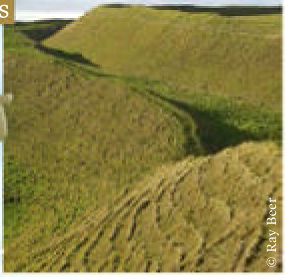
MOST DEFENSIVE

3. Durotriges

Located: Dorset

Facts: A southern tribe, the Durotriges differed from others by remaining largely in hill forts long after others had abandoned them. They were huge traders and, through numerous harbours, exchanged many goods with the Romans.

Maiden Castle, a great example of an Iron Age, multi-ditch hill fort


© Ray Beer

Ancient Greek theatres

Discover how these massive amphitheatres were built and used

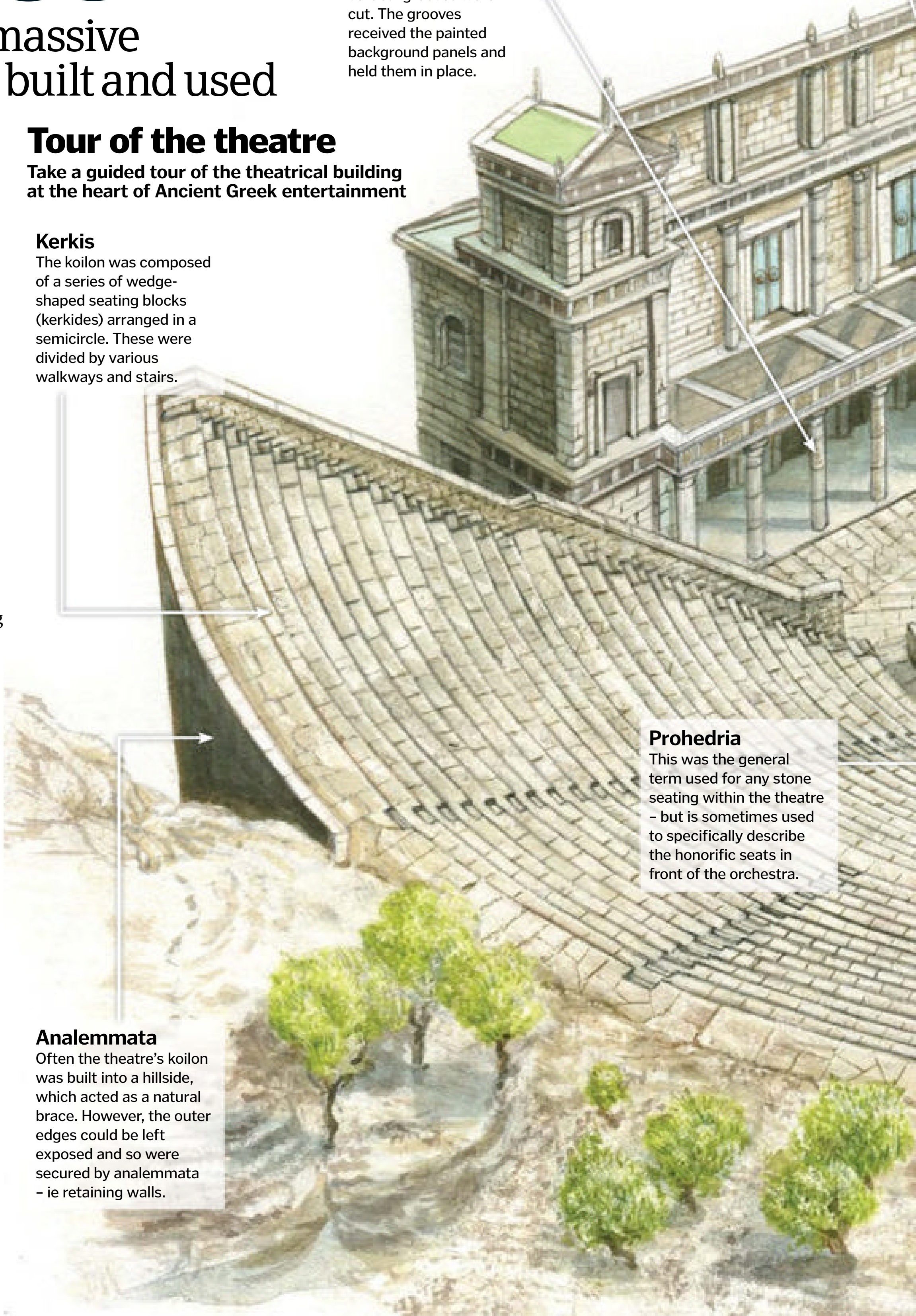
With the invention of tragedies in the late-sixth century BCE, comedies in the fifth century BCE and the satyr play tragicomedies around the first century BCE, the Ancient Greeks had to build a huge number of impressive theatres to do their plays justice. As the centuries went on – and the popularity of the theatre grew and grew – the buildings had to expand and adapt to meet the demand. Indeed, many of these semicircular amphitheatres could seat well over 10,000 people and were used frequently during religious festivals such as the Dionysia, a major celebration centred around the god Dionysus.

While the theatres of the Ancient Greeks began as simple clearings with a smattering of wooden benches for the audience to sit on, before long they had grown into full-blown sanctuary-like facilities. These included large banks of stone seats, a vast orchestra and acting area, a complex backstage network of rooms, entrances and trapdoors, as well as a wide selection of ornate and decorative scenic backdrops. These features, along with the Ancient Greeks' love for festivals, led theatres to take a central role in cementing and spreading Greek culture – something the Romans would later adopt for themselves.

Theatres were made primarily out of stone, often with the amphitheatre's seats placed into the side of a hill for extra support, while traditional construction methods for civic buildings and temples were transferred for the production of colonnades, scenery and entranceways. Interestingly, the greatest technical feat in constructing many of these theatres were the excellent acoustics, with the shape and angle of the seating arrangement and materials (limestone was a popular choice, for instance) serving as acoustic traps. These would filter out low-frequency sounds like spectator chatter and enhance the high frequencies of the performers' voices.

Tour of the theatre

Take a guided tour of the theatrical building at the heart of Ancient Greek entertainment



Episkenion
The upper storey of the skene. Accessed by a ramp or stairwells, it provided an additional acting/singing space.

Thyroma
These structures were stone pillars into which vertical grooves were cut. The grooves received the painted background panels and held them in place.

Kerkis
The koilon was composed of a series of wedge-shaped seating blocks (kerkides) arranged in a semicircle. These were divided by various walkways and stairs.

Prohedria
This was the general term used for any stone seating within the theatre – but is sometimes used to specifically describe the honorific seats in front of the orchestra.

Analemmata
Often the theatre's koilon was built into a hillside, which acted as a natural brace. However, the outer edges could be left exposed and so were secured by analemmata – ie retaining walls.

HEAD 2 HEAD
ANCIENT GREEK THEATRES

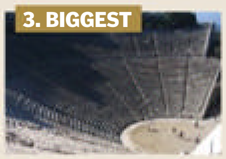
1. BIG

Theatre of Delphi
Located behind the Temple of Apollo in the Sanctuary of Delphi, this theatre has 35 rows of seats for spectators.

2. BIGGER

Odeon of Herodes Atticus
With a capacity of 5,000, the Odeon is located on the Acropolis in Athens, Greece, and is still used for performances today.

3. BIGGEST



Theatre of Epidaurus
Built in the fourth century BCE and able to seat 15,000, this theatre is one of the largest classical examples in the world.

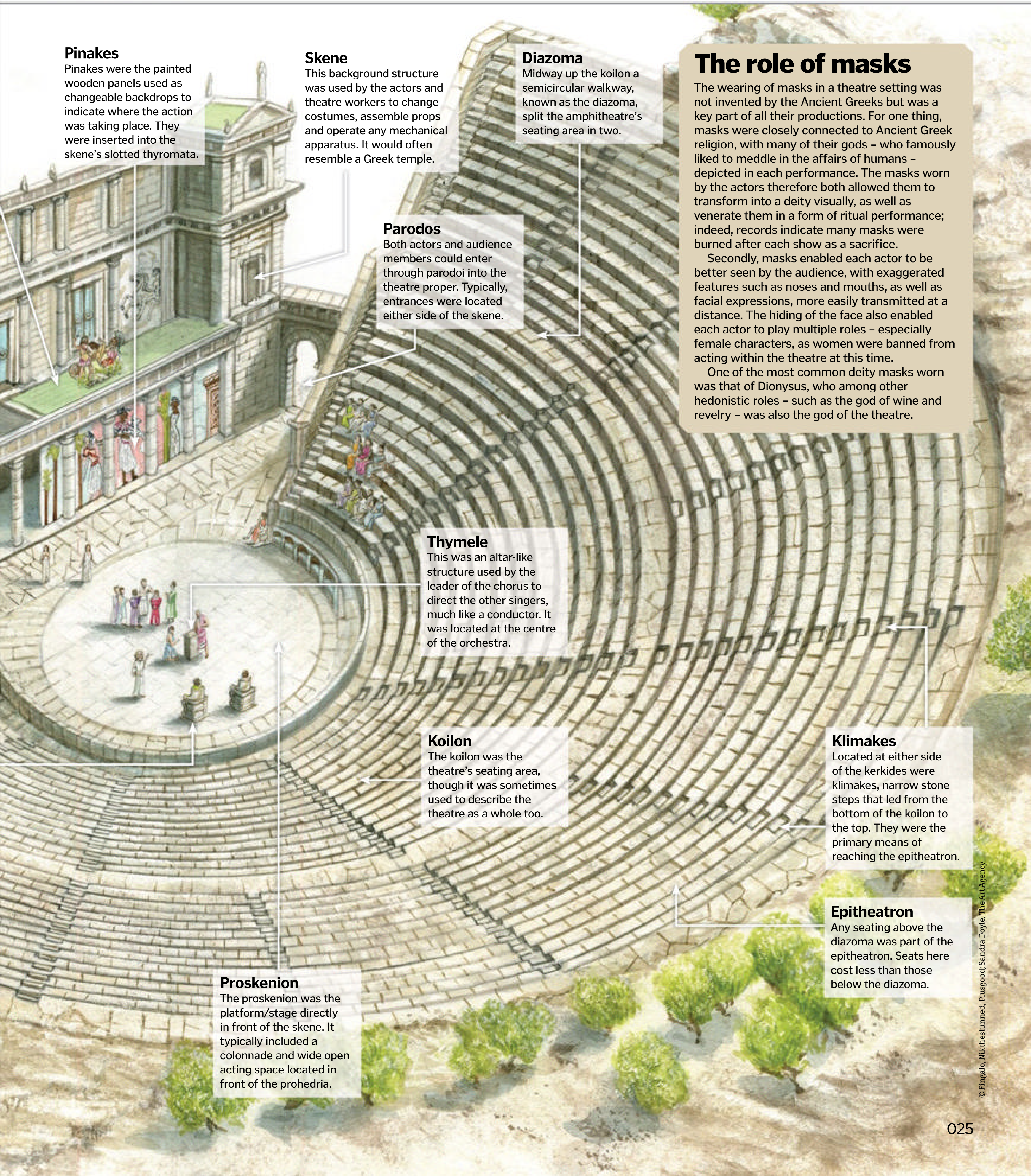
DID YOU KNOW? *Members of Ancient Greek acting guilds were referred to as 'technitai'*

The role of masks

The wearing of masks in a theatre setting was not invented by the Ancient Greeks but was a key part of all their productions. For one thing, masks were closely connected to Ancient Greek religion, with many of their gods – who famously liked to meddle in the affairs of humans – depicted in each performance. The masks worn by the actors therefore both allowed them to transform into a deity visually, as well as venerate them in a form of ritual performance; indeed, records indicate many masks were burned after each show as a sacrifice.

Secondly, masks enabled each actor to be better seen by the audience, with exaggerated features such as noses and mouths, as well as facial expressions, more easily transmitted at a distance. The hiding of the face also enabled each actor to play multiple roles – especially female characters, as women were banned from acting within the theatre at this time.

One of the most common deity masks worn was that of Dionysus, who among other hedonistic roles – such as the god of wine and revelry – was also the god of the theatre.



Pinakes
Pinakes were the painted wooden panels used as changeable backdrops to indicate where the action was taking place. They were inserted into the skene's slotted thyromata.

Skene
This background structure was used by the actors and theatre workers to change costumes, assemble props and operate any mechanical apparatus. It would often resemble a Greek temple.

Diazoma
Midway up the koilon a semicircular walkway, known as the diazoma, split the amphitheatre's seating area in two.

Parodos
Both actors and audience members could enter through parodoi into the theatre proper. Typically, entrances were located either side of the skene.

Thymele
This was an altar-like structure used by the leader of the chorus to direct the other singers, much like a conductor. It was located at the centre of the orchestra.

Koilon
The koilon was the theatre's seating area, though it was sometimes used to describe the theatre as a whole too.

Klimakes
Located at either side of the kerkides were klimakes, narrow stone steps that led from the bottom of the koilon to the top. They were the primary means of reaching the epitheatron.

Epitheatron
Any seating above the diazoma was part of the epitheatron. Seats here cost less than those below the diazoma.

Proskenion
The proskenion was the platform/stage directly in front of the skene. It typically included a colonnade and wide open acting space located in front of the prohedria.

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Greek tomb construction

Learn about the unique structures in which the elite of these Ancient Greek people were buried

There were two main types of Mycenaean tomb: chamber tombs and tholos tombs. The former predates the latter and consisted of a rhomboidal chamber cut into rock/earth and finished with a square stone pyramid on the top. No examples of these tombs have been found in modern times, however they are detailed in ledgers of the ancient Babylonian city of Uruk.

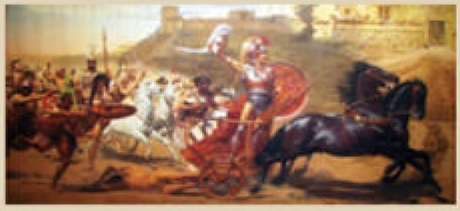
The latter, which became the more common tomb after 1500 BCE, is of a grander design. Tholos tombs, which resemble the shape of a beehive, were conical, false-domed chambers built out of mud bricks and stone. The bricks were laid in a circle on top of one another up to a tapered centre point. The entire dome was then covered by an earthen mound (tumulus).

These beehive tombs were accessed via a long approach corridor, or passage, that was known as a dromos, which culminated in a large entranceway, called a stomion. The stomion consisted of a large rectangular brick opening commonly flanked by two stone columns and topped with a single giant stone mantle. Above the mantle a triangular hole was often filled with a decorative relief sculpture.

Inside, off the main conical chamber, lay an antechamber, which was typically rectangular. This could be used either for burials – other family members – or more likely grave goods, such as jewellery and weapons. There's evidence that both the antechamber and main stomion were installed with wooden doors, the latter set slightly back from the main façade.

Who were the Mycenaeans?

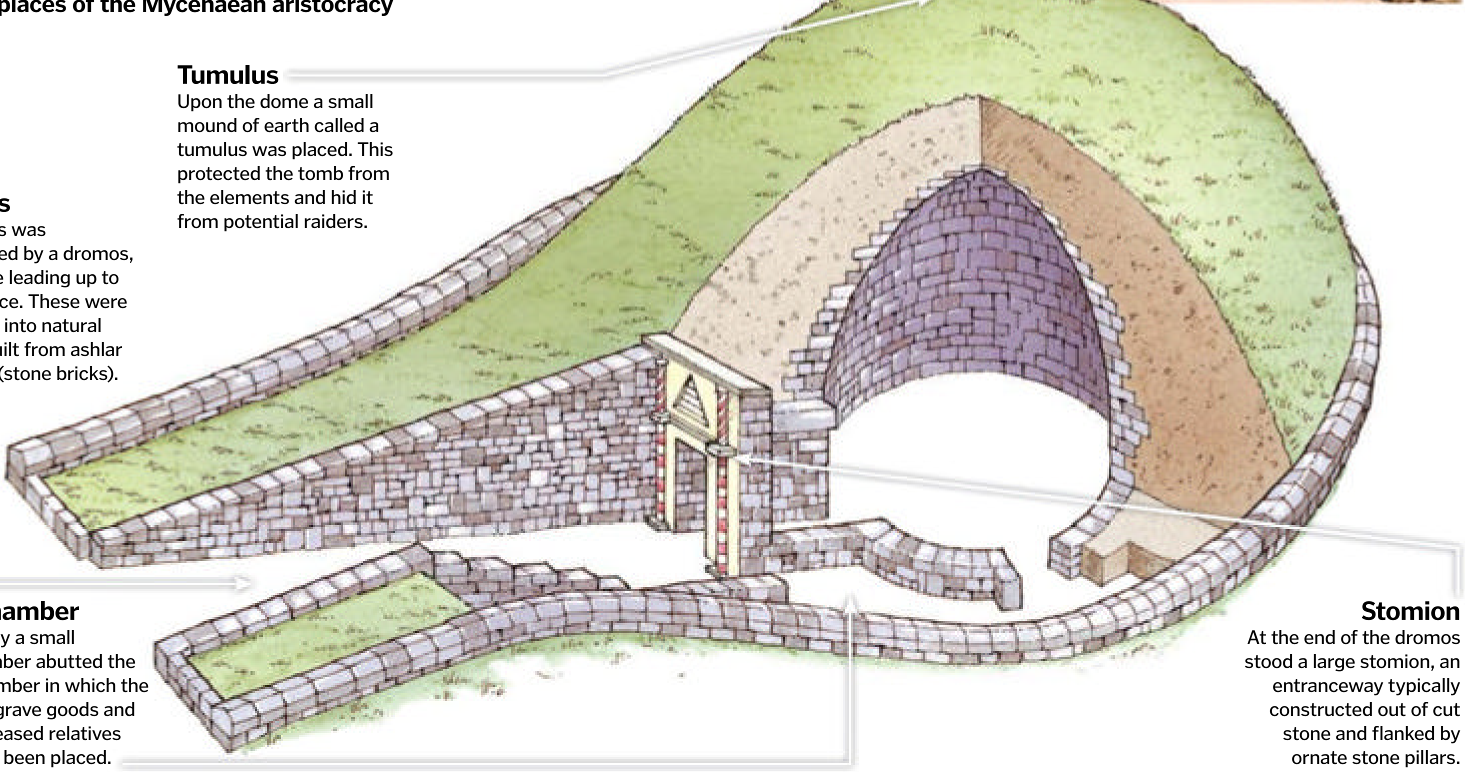
The Mycenaean civilisation occupied much of modern-day central Greece and flourished between 1600 and 1100 BCE. Unlike the earlier Minoan settlers of the area whose society expanded and prospered through trade, the Mycenaeans advanced theirs through military conquest. One of the most notable examples of the Mycenaean expansion through war is recorded in Homer's *The Iliad*, where the king of Mycenae, Agamemnon, and the united forces of Greece took the city of Ilium (Troy) in north-west Anatolia (Turkey). Another advance saw the Mycenaeans capture the island of Crete.



© DK Images; Thinkstock

A tholos tomb unearthed

Discover the major elements that made up the final resting places of the Mycenaean aristocracy



Tumulus
Upon the dome a small mound of earth called a tumulus was placed. This protected the tomb from the elements and hid it from potential raiders.

Dromos
The tholos was approached by a dromos, an avenue leading up to its entrance. These were either cut into natural rock or built from ashlar masonry (stone bricks).

Antechamber
Commonly a small antechamber abutted the main chamber in which the person's grave goods and even deceased relatives may have been placed.

Stomion
At the end of the dromos stood a large stomion, an entranceway typically constructed out of cut stone and flanked by ornate stone pillars.

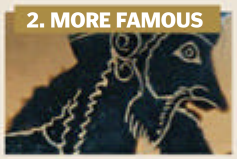
HEAD 2 HEAD HOMERIC HEROES

1. FAMOUS

Ajax

A mythological hero and key player in Homer's *Iliad*, Ajax is a warrior with the strength of many men. During the story he kills a lot of Trojan warriors.

2. MORE FAMOUS



Agamemnon

Also in the *Iliad*, but suspected by some to be real, Agamemnon was a warrior king of Mycenae. He was commander-in-chief of the Greek forces.

3. MOST FAMOUS

Heracles

A divine hero in Greek mythology, Heracles was Earth's greatest warrior. During his 12 Labours, he killed the Nemean lion and a nine-headed hydra.

DID YOU KNOW? *Panoply is the term used to describe a complete set of hoplite armour and weaponry*

Greek warriors

The hoplites of Ancient Greece were some of the most feared fighters in the world – find out why they were so hard to defeat

Both in Homeric and post-Homeric Greece, hoplite warriors were considered the most deadly and efficient soldiers on the planet. Armed with a variety of highly refined weapons – such as spears, swords and daggers, protected by toughened bronze armour and adept at executing cunning tactics and formations, these Ancient Greek warriors tore through many an enemy army with considerable ease.

Arguably, hoplites really came into their own around the sixth century BCE. Prior to this point Greek warriors – who were self-armed and trained civilians – fought for personal, familial or national honour singularly. They obviously grouped under city-state banners to wage wars, but when the battle started, the onus was very much on man-to-man single combat; indeed, many battles of this period began with army commanders/heroes facing off against each other solo.

After the introduction of advanced military formations such as the phalanx – see 'Wall of death' boxout for more – circa 700 BCE, soldiers began to fight battles as cohesive military units.

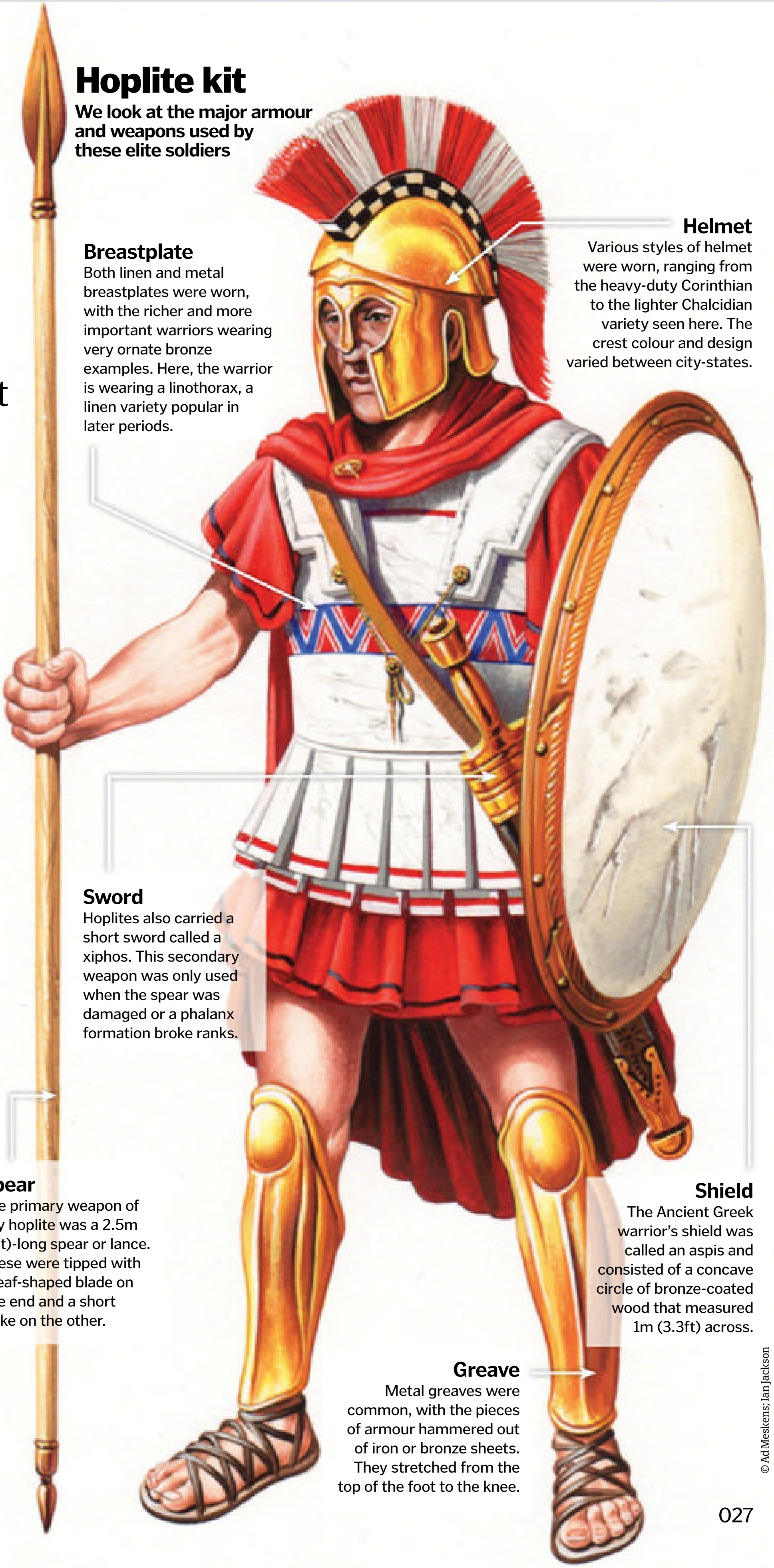
This increased their battle prowess further and, by the time of the massive Persian invasion of 480 BCE, enabled them to win a series of decisive battles against forces that, going on the numbers, they should have lost.

Wall of death

Aside from their good training, weapons and armour, a key reason hoplite warriors were so feared was their use of formations. Chief among these was the phalanx, a rectangular mass formation composed of heavy infantry that, by engaging the enemy as one, allowed the warriors to effectively crush any foe in their path. The phalanx was created by arranging hoplites in lines typically eight to ten men deep, with the front rank of soldiers interlocking their shields together. The long rectangular body of soldiers would then slowly advance, spears outstretched, skewering any enemies ahead.

Hoplite kit

We look at the major armour and weapons used by these elite soldiers



Helmet
Various styles of helmet were worn, ranging from the heavy-duty Corinthian to the lighter Chalcidian variety seen here. The crest colour and design varied between city-states.

Breastplate
Both linen and metal breastplates were worn, with the richer and more important warriors wearing very ornate bronze examples. Here, the warrior is wearing a linothorax, a linen variety popular in later periods.

Sword
Hoplites also carried a short sword called a xiphos. This secondary weapon was only used when the spear was damaged or a phalanx formation broke ranks.

Spear
The primary weapon of any hoplite was a 2.5m (8ft)-long spear or lance. These were tipped with a leaf-shaped blade on one end and a short spike on the other.

Shield
The Ancient Greek warrior's shield was called an aspis and consisted of a concave circle of bronze-coated wood that measured 1m (3.3ft) across.

Greave
Metal greaves were common, with the pieces of armour hammered out of iron or bronze sheets. They stretched from the top of the foot to the knee.

© Ad Meskens; Ian Jackson

Aztec warriors

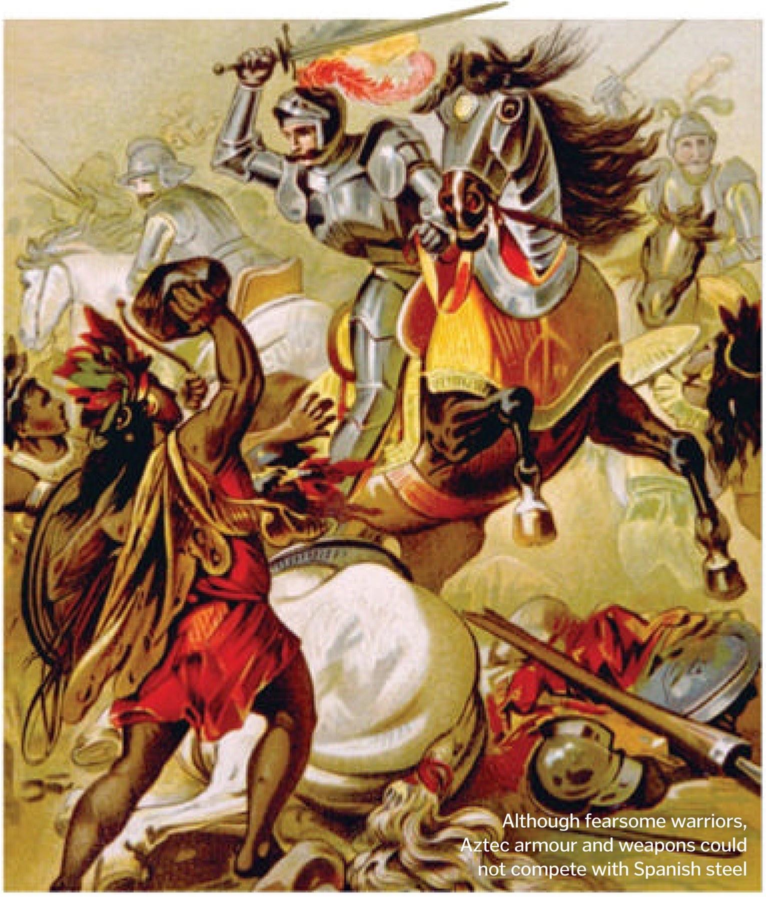
Ready yourself for battle as you learn about the martial side of this Central American civilisation

The Aztecs were a fierce and powerful group of warriors, defined by their religious fervour and class system.

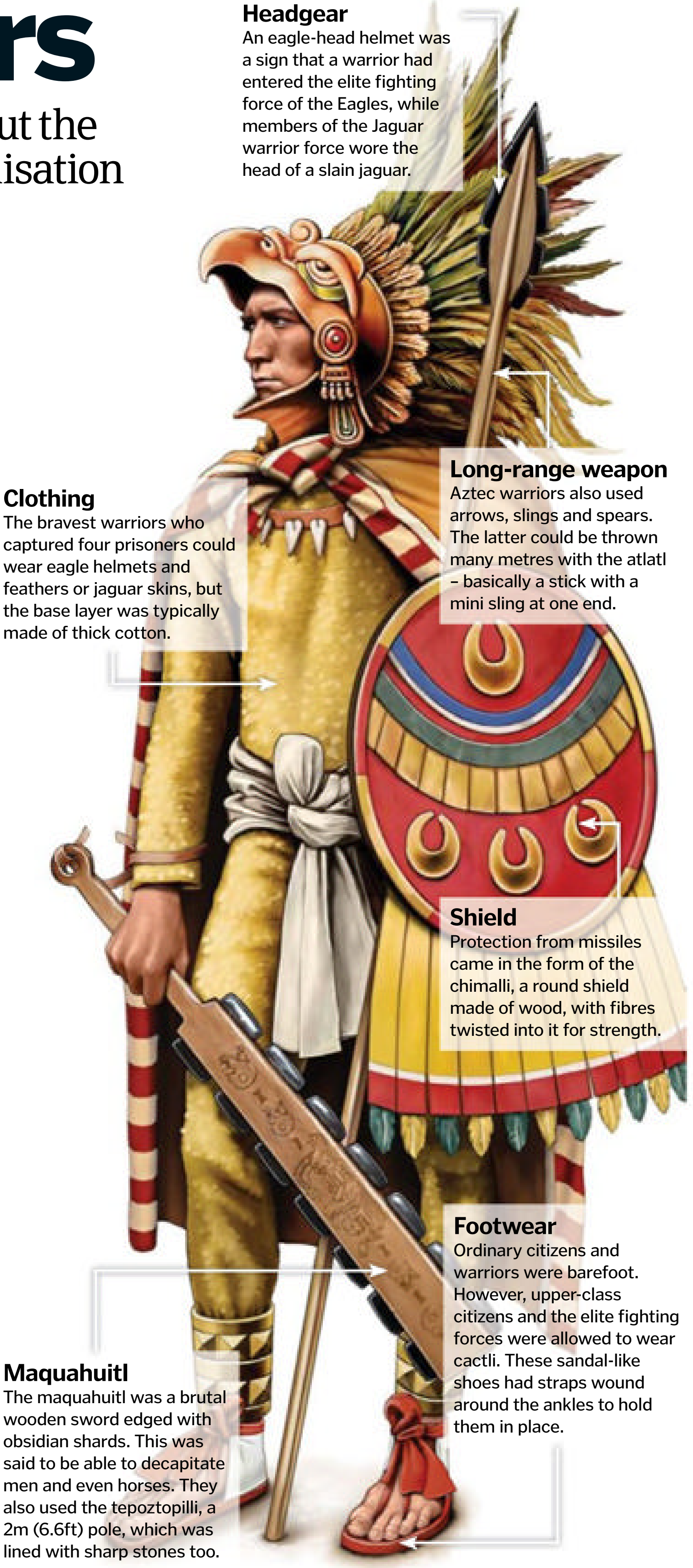
New warriors had to work their way up from the bottom by capturing prisoners. This was an important part of a young warrior's introduction into the martial society, as the Aztecs would sacrifice prisoners to the god Huitzilopochtli. Once a warrior had captured a prisoner, he would attain the rank of a warrior.

Most Aztecs wore padded cotton armour called ichcahuipilli, which remained cool in the intense heat of Mexico but was also tough enough to deflect most arrows and darts. However, the elite fighting forces – called the 'Eagles' and 'Jaguars' – dressed as their namesakes. Eagle warriors donned feathers and an eagle-head helmet (see annotated warrior), while Jaguar fighters were wrapped in the skin of the South American big cat. The higher up the social rank you rose, the more elaborate the costume became.

Their main weapon was the maquahuitl, a wooden sword with vicious shards of obsidian embedded down the sides. This deadly tool was capable of beheading a human. The Aztecs were also proficient users of arrows, slings and the atlatl, a throwing device that allowed them to hurl spears harder and faster than possible with the arm alone.



Although fearsome warriors, Aztec armour and weapons could not compete with Spanish steel



Headgear
An eagle-head helmet was a sign that a warrior had entered the elite fighting force of the Eagles, while members of the Jaguar warrior force wore the head of a slain jaguar.

Clothing
The bravest warriors who captured four prisoners could wear eagle helmets and feathers or jaguar skins, but the base layer was typically made of thick cotton.

Long-range weapon
Aztec warriors also used arrows, slings and spears. The latter could be thrown many metres with the atlatl – basically a stick with a mini sling at one end.

Shield
Protection from missiles came in the form of the chimalli, a round shield made of wood, with fibres twisted into it for strength.

Footwear
Ordinary citizens and warriors were barefoot. However, upper-class citizens and the elite fighting forces were allowed to wear cactli. These sandal-like shoes had straps wound around the ankles to hold them in place.

Maquahuitl
The maquahuitl was a brutal wooden sword edged with obsidian shards. This was said to be able to decapitate men and even horses. They also used the tepoztopilli, a 2m (6.6ft) pole, which was lined with sharp stones too.

© Jean-Michel Girard/The Art Agency; Alamy

STRANGE BUT TRUE
BULLISH BEHAVIOUR

What did tribal chief Sitting Bull do after he surrendered?

A Move to Canada **B** Open a shop **C** Join a circus

Answer:
In 1885 Sitting Bull became an attraction at Buffalo Bill's Wild West show, riding around in traditional Native American garb and posing for pictures and signing autographs. Allegedly, he would curse the audience in his native tongue.

DID YOU KNOW? *Despite the stereotype, only a select few Native American tribes practised scalping*

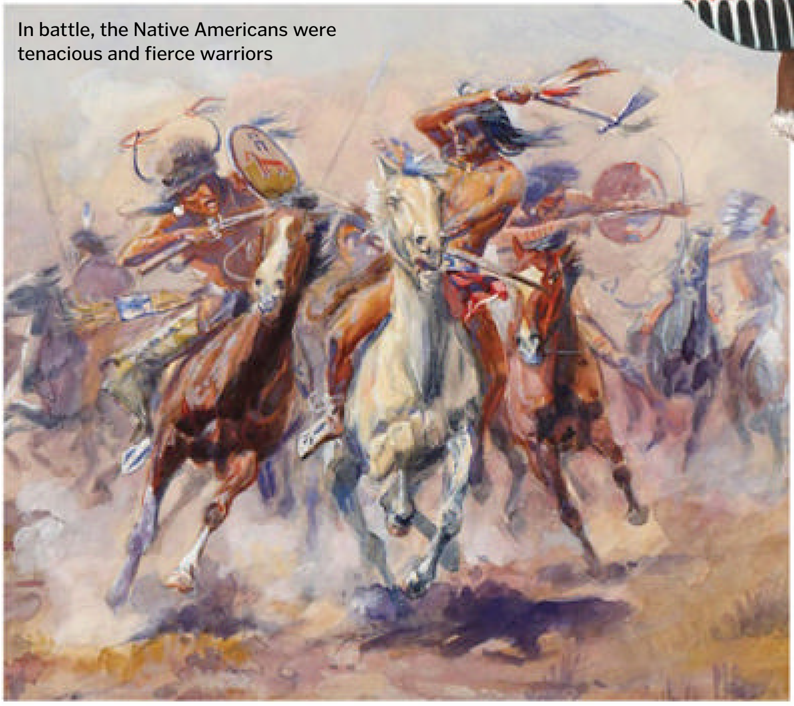
Native American warrior

Check out the key kit as carried by a fighter from the Dakota Sioux tribe

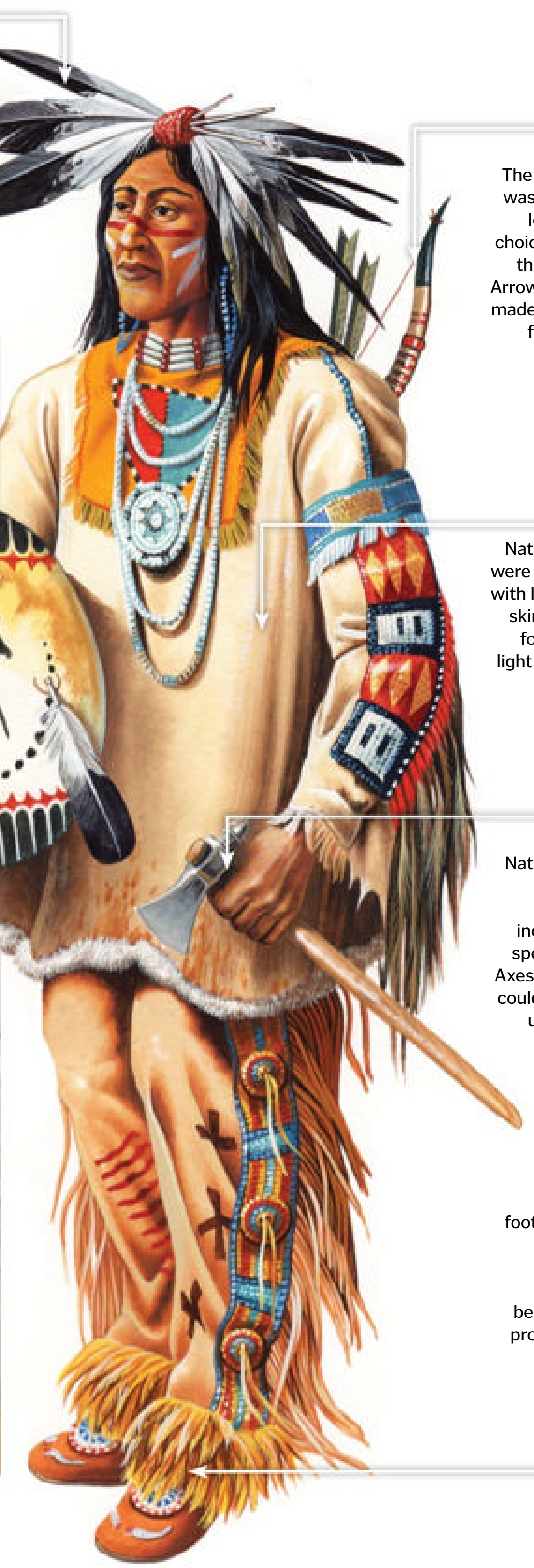
Despite being lightly armoured, Native American warriors were fierce combatants, well-trained in both hand-to-hand and ranged combat. Armed with a selection of bows, spears, swords, daggers, axes and even – in the later decades of the 19th century – guns, Westerners coming to claim the Indians' land were in for a shock.

Indeed, despite their superior firepower, armour and resources, British and American armies often found themselves outmanoeuvred and outfought, with the Native American warriors' expert horsemanship skills allowing them to strike quickly and with deadly precision, taking out large swathes of the invading forces before retreating to the safety granted by their knowledge of the territory.

Both the Native Americans' excellent combat skills and innovative use of terrain in battle tactics meant that it took the British and then Americans over 150 years to evict all of the Native American tribes in North America onto the reservations that many of their descendants inhabit today. And they did so at great cost, with thousands of soldiers being cut down by their fierce and agile opposition right up until the turn of the 20th century.



In battle, the Native Americans were tenacious and fierce warriors



Headgear
Unlike many modern depictions of Native American warriors, they did not enter battle wearing grand headpieces. Instead, a simple selection of bird feathers was worn in the hair, while the face and body would be covered with war-paint.

Shield
The only form of protection against incoming missiles, a small circular wooden shield covered with animal skins and/or leather could be used to deflect arrows.

Long-range weapon
The short bow and arrow was the Native American long-range weapon of choice – something which they used with aplomb. Arrowheads were typically made of iron, while the tail feathers of birds were used as fins.

Clothing
Native American warriors were not heavily armoured, with leather, fur and animal skins providing their only form of protection. This light armour granted them excellent agility and manoeuvrability.

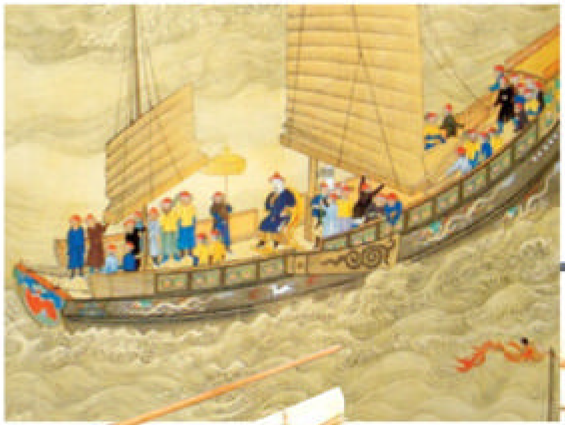
Hand-to-hand weapon
Native American warriors carried a variety of handheld weaponry, including axes, daggers, spears and even swords. Axes were popular, as they could be thrown as well as used in melee combat.

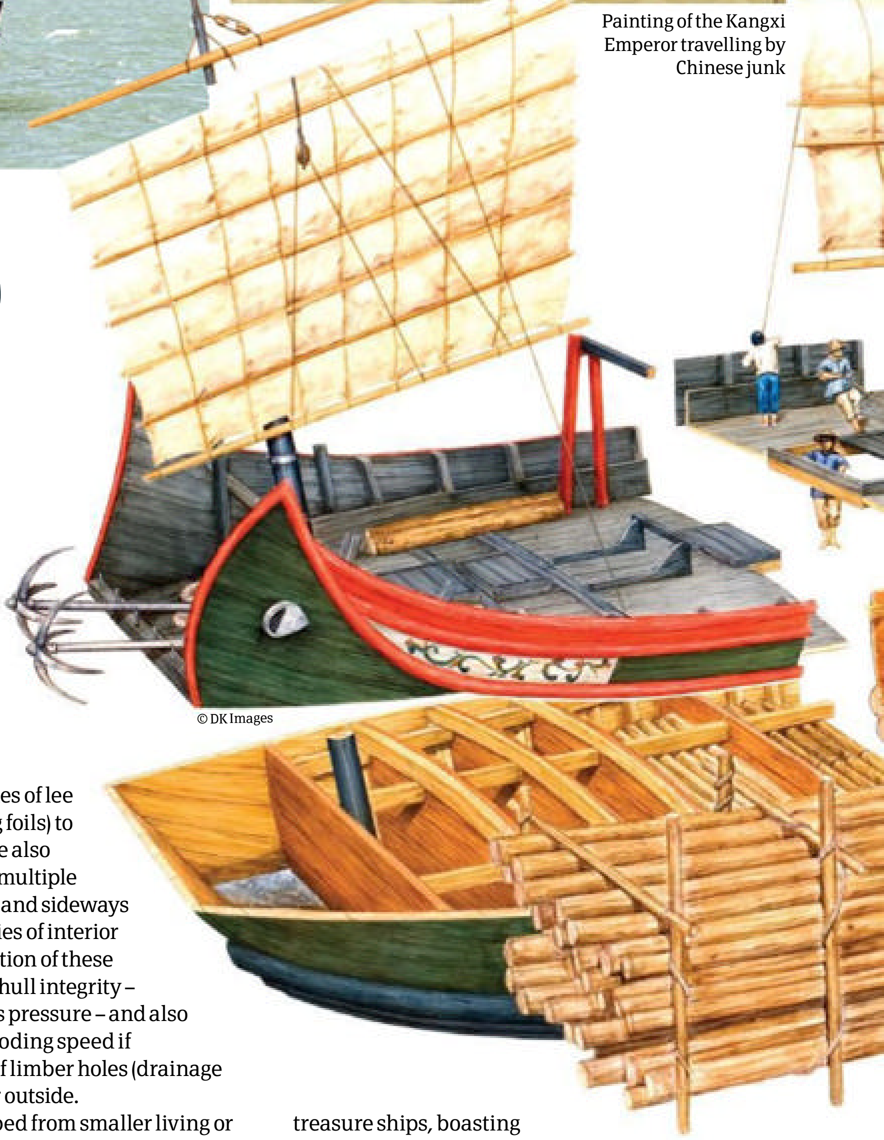
Footwear
Moccasins were the footwear of choice. Made from soft leather or deerskin and adorned with embroidery and beading, they offered no protection but were light and comfortable.

© Ian Jackson

Inside the iconic Chinese vessel

© Remi Jouan


Painting of the Kangxi Emperor travelling by Chinese junk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Chinese junks

Highly versatile, the Chinese junk has been used since the second Century AD, granting dynamic sailing controls and high speed

Chinese junks – variously sized trading and transportation ships used in Asia from the second Century AD to the modern day – work by partnering a sturdy keelless hull with a versatile and mobile sail-plan, in order to generate a fast and highly stable sailing platform.

The sail-plan of a junk differs from that of traditional square-rigged ships, with the junk's various sails capable of being moved inwards towards the ship's lengthy central axis, allowing it to be easily modified in order to sail into the wind. The sails themselves also differ from the traditional variety, with long horizontal struts called battens providing a rigid shape – akin to that of Venetian blinds – and greater tear-resistance in high wind. Further increasing the power and speed of a junk is its tendency to spread its sails over multiple masts, with five or more common on larger vessels.

Junk hulls were traditionally constructed from softwoods such as cedar and sported a horseshoe-shaped stern, elevated poop deck and flat base with no keel. Due to this, junk hulls are fitted with an overly large keel and series of lee and centreboards (lifting foils) to remain stable. Hulls were also strengthened greatly by multiple partitioning lengthways and sideways internally, creating a series of interior compartments. The addition of these matrix braces increased hull integrity – especially from sideways pressure – and also dramatically reduced flooding speed if breached, with a series of limber holes (drainage holes) transferring water outside.

Chinese junks developed from smaller living or fishing boats such as sampans in the Han Dynasty of 206 BCE-220 AD, being used primarily to traverse inland waterways and coastal waters. However, by the 15th Century AD their size and role had evolved massively into trans-continent trading and military vessels, carrying hundreds of men and tons of products. Indeed, according to Chinese historical documentation, during the missions of renowned explorer and mariner Zheng He, junks had been transformed into 420-feet long, 180-feet wide treasure ships, boasting nine masts and crewed by over 130 men. During He's 1405 tour of the Indian Ocean, the explorer commanded over 300 junks and 30,000 men.

Today, the role of junks has diminished from its military and trading height due to the rise of modern technology and transportation methods. However, they are still commonly used by civilians to fish, commute, trade and travel, as well as by tourists who board them on sightseeing tours.

5 TOP FACTS JUNKS

Taiwan San

1 In 1955, six men sailed a Ming Dynasty-style replica junk 6,000 miles from Taiwan to San Francisco. In 1959, Catalan men also used a junk to sail from Hong Kong to Barcelona.

Junco

2 The word entered the English language in the mid 17th Century via the Portuguese word 'junco'. Other names include 'jong' in Malay and 'chuán' in Mandarin.

da Conti

3 During his expeditions in Asia (1419-1444), Venetian merchant and explorer Niccolo da Conti sighted junks weighing over 2,000 tons with five sails and multiple masts.

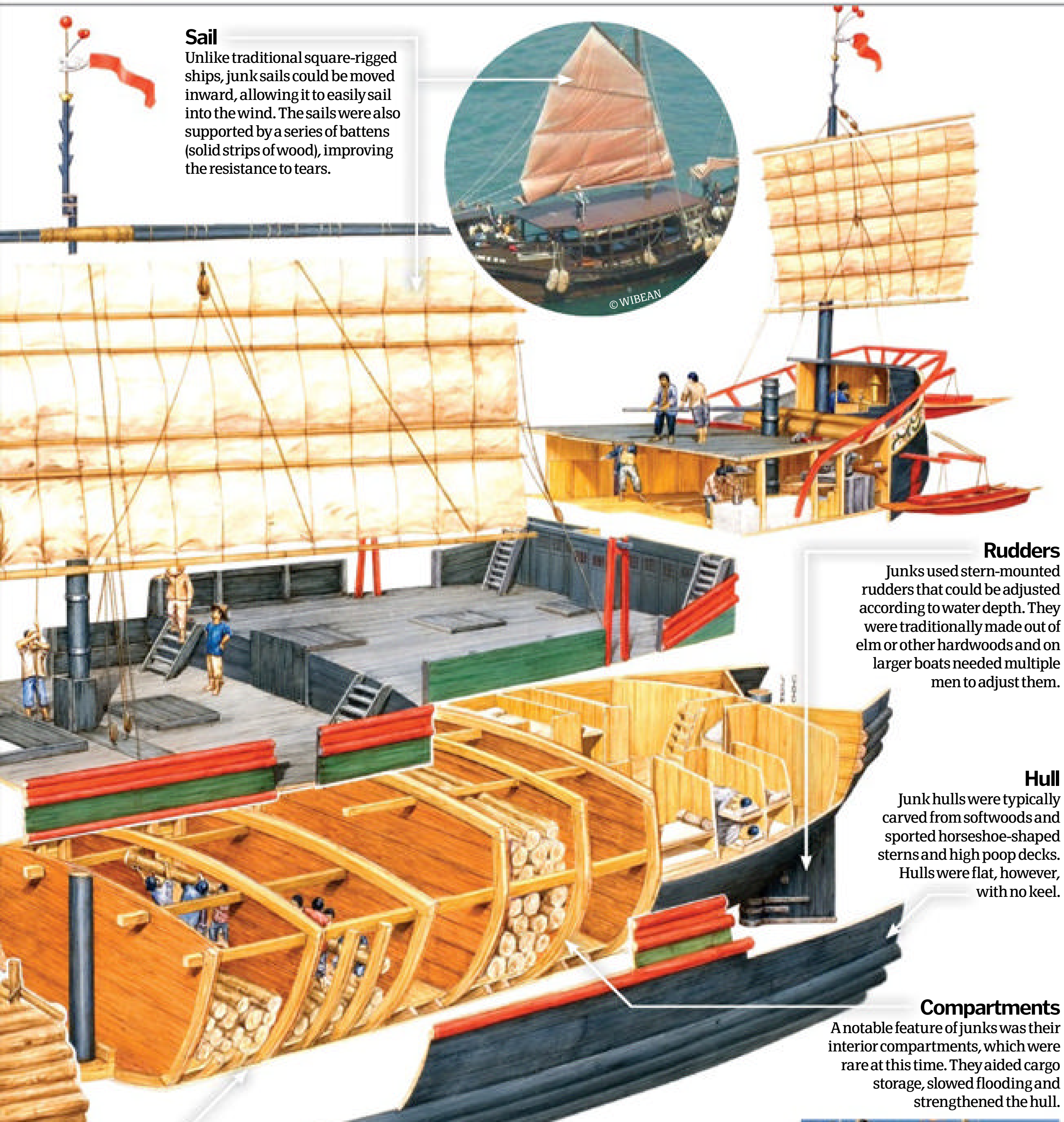
Trade

4 The primary use of Chinese junks were as trading vessels. According to Richard Cocks, head of the English trading factory in Hirado, over 60 junks visited Nagasaki in 1612.

Origami

5 One of the most famous origami designs of all time is called the Chinese junk, a multi-stage folding method to create four distinct objects from one sheet of paper.

DID YOU KNOW? Chinese junks developed in the Han Dynasty of 206 BCE-220 AD



Sail

Unlike traditional square-rigged ships, junk sails could be moved inward, allowing it to easily sail into the wind. The sails were also supported by a series of battens (solid strips of wood), improving the resistance to tears.

Rudders

Junks used stern-mounted rudders that could be adjusted according to water depth. They were traditionally made out of elm or other hardwoods and on larger boats needed multiple men to adjust them.

Hull

Junk hulls were typically carved from softwoods and sported horseshoe-shaped sterns and high poop decks. Hulls were flat, however, with no keel.

Compartments

A notable feature of junks was their interior compartments, which were rare at this time. They aided cargo storage, slowed flooding and strengthened the hull.

Lee/centreboards (not shown)

Leeboards and centreboards were used to stabilise the junk and improve its capability to sail upwind.

The design spread through Asia, as seen in this Vietnamese variant

© Thomas Schoch

Traditionally junks were made from softwoods

2 x © Paul A. Hernandez

Head to Head

TRADING VESSEL EVOLUTION

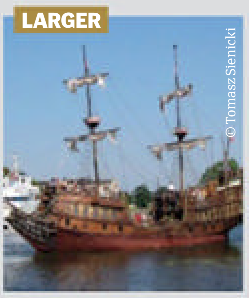
LARGE

© Bernard Gagnon

Junk

Along with sampans, junk ships developed from smaller fishing vessels. Their flat-bottomed design and Venetian blind-type sails allowed them to remain stable in rough conditions and sail against the wind with great ease. They originated in Asia but spread throughout the Middle East and Africa through trade in the early centuries AD.

LARGER

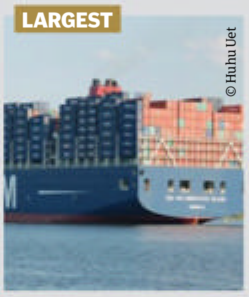


© Tomasz Sienicki

Galleon

Evolving from the carrack – the predominant sailing vessel of the 14th and 15th Century – the galleon was a multi-decked ship used for warfare and trade. Galleons developed in Portugal and Spain in the 16th Century and were used throughout Europe, Africa and the Caribbean to transport goods along trade routes.

LARGEST



© Huhu Uet

Freighter

The predominant method used today to trade by sea over long distances, freighters can carry hundreds of tons' worth of metal containers filled with goods. These container ships were developed in the middle of the 20th Century and now account for 90 per cent of worldwide trade in non-bulk goods.

The ancient Celts

How the Iron Age revolutionised this pre-Roman civilisation

The discovery of how to extract iron from its ore changed the world. As the Iron Age was born, new tools could be made for warfare, agriculture, hunting and fishing. Among the main beneficiaries of this new age were the Celts. The Iron Age in Europe lasted from 800 BCE until 43 CE and signalled a significant development of society.

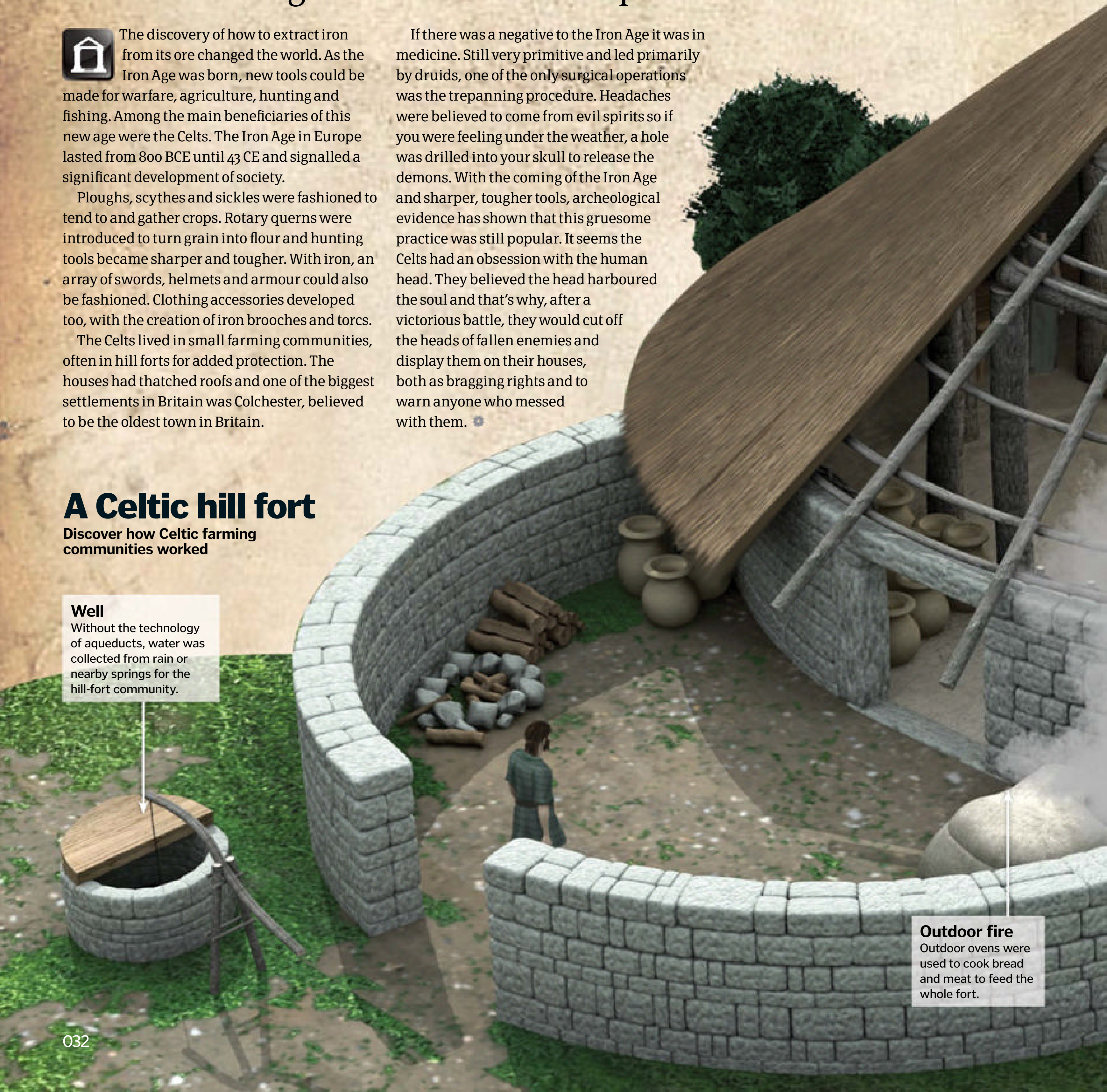
Ploughs, scythes and sickles were fashioned to tend to and gather crops. Rotary querns were introduced to turn grain into flour and hunting tools became sharper and tougher. With iron, an array of swords, helmets and armour could also be fashioned. Clothing accessories developed too, with the creation of iron brooches and torcs.

The Celts lived in small farming communities, often in hill forts for added protection. The houses had thatched roofs and one of the biggest settlements in Britain was Colchester, believed to be the oldest town in Britain.

If there was a negative to the Iron Age it was in medicine. Still very primitive and led primarily by druids, one of the only surgical operations was the trepanning procedure. Headaches were believed to come from evil spirits so if you were feeling under the weather, a hole was drilled into your skull to release the demons. With the coming of the Iron Age and sharper, tougher tools, archeological evidence has shown that this gruesome practice was still popular. It seems the Celts had an obsession with the human head. They believed the head harboured the soul and that's why, after a victorious battle, they would cut off the heads of fallen enemies and display them on their houses, both as bragging rights and to warn anyone who messed with them.

A Celtic hill fort

Discover how Celtic farming communities worked



Well
Without the technology of aqueducts, water was collected from rain or nearby springs for the hill-fort community.

Outdoor fire
Outdoor ovens were used to cook bread and meat to feed the whole fort.

5 TOP FACTS BRITISH CELTS

Iceni
1 Famous for being led by Boudicca, the Iceni were located in modern-day East Anglia and were a wealthy, warlike people who led many revolts against Roman rule.

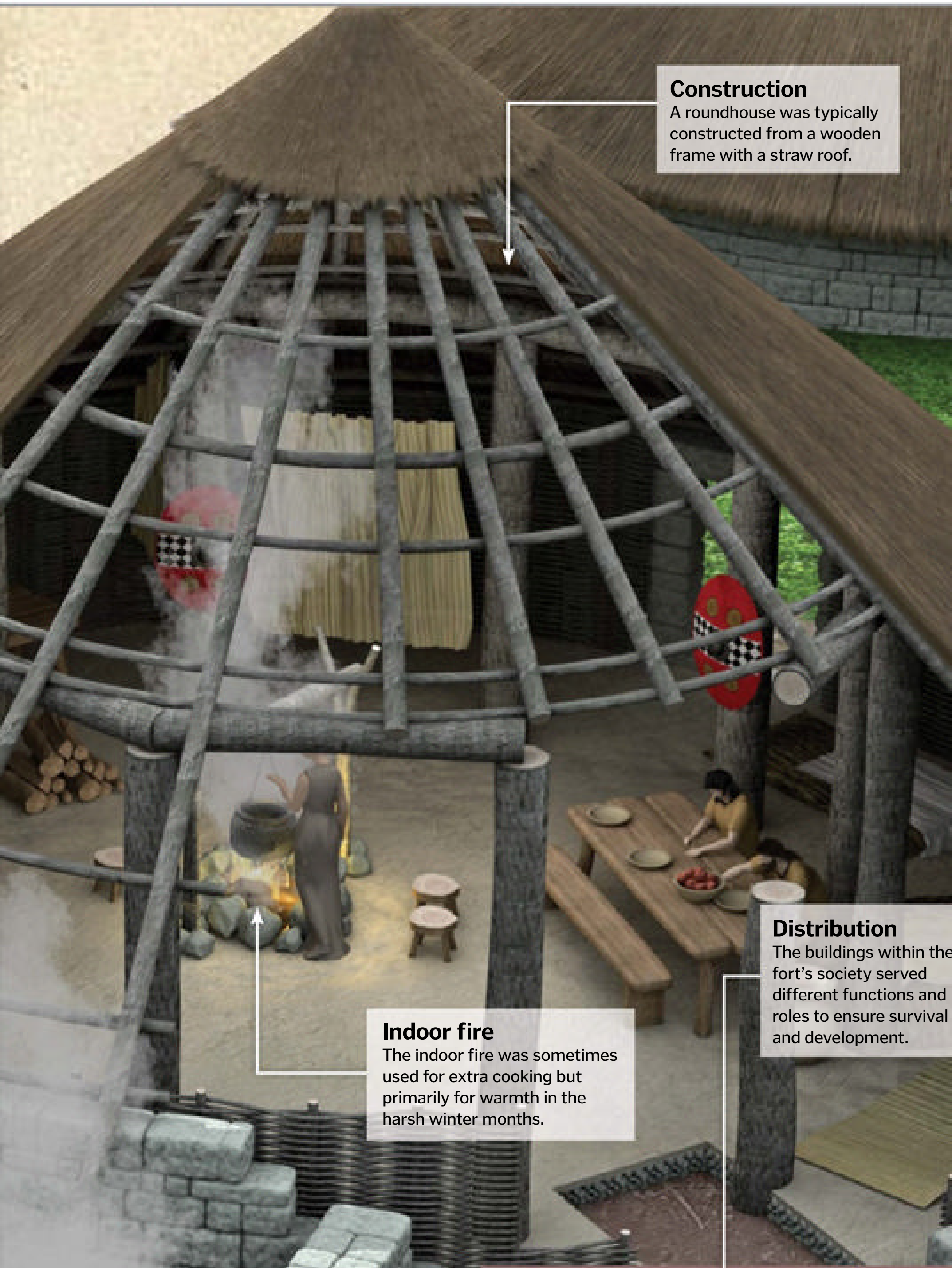
Dobunni
2 This tribe was one of the largest in Britain and resided on the modern English-Welsh border. Unlike many others, the Dobunni easily submitted to Roman rule.

Dumnonii
3 Occupying Cornwall, Devon and Somerset, the Dumnonii favoured small farms over larger settlements and preferred healthy relations with Brittany in France.

Catuvellauni
4 One of the most powerful tribes, the Catuvellauni were made out of several smaller groups. Supporting Roman rule, Verulamium (St Albans) was a big Roman settlement.

Silures
5 After the Iceni, this band of Celts gave the Romans the most trouble. Originating in the valleys of South Wales, they were described as a strong and warlike nation.

DID YOU KNOW? *Female Celts had just as many rights as men. They would fight, own land and achieve status*



Construction
A roundhouse was typically constructed from a wooden frame with a straw roof.

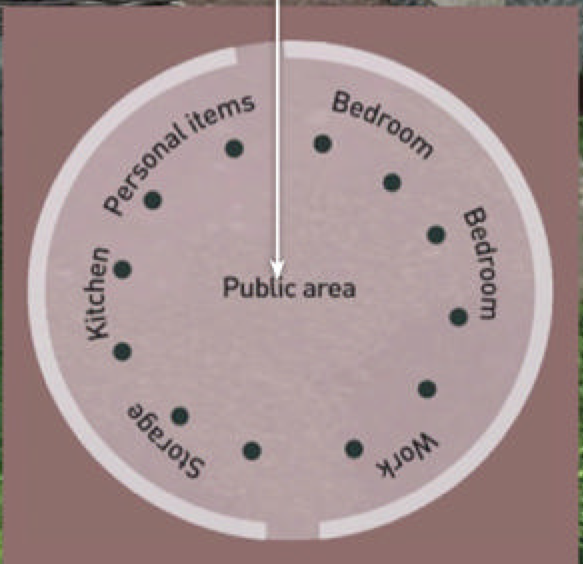
Indoor fire
The indoor fire was sometimes used for extra cooking but primarily for warmth in the harsh winter months.

Hill fort location
Often surrounded by a wooden or stone wall, both natural and man-made defences made the fort tricky for enemies to breach.

A reconstructed roundhouse like the ones Celts lived in

Celtic cities
Celts lived in small communities led by a chieftain and a band of warriors. There were few alliances among the different tribes and no sort of centralised state or government.

Distribution
The buildings within the fort's society served different functions and roles to ensure survival and development.



Who were the Celts?

A term used for many different tribes, the Celts varied from region to region. For instance, the Gauls were based in what is now France and the Celtiberians were located in modern day Spain and Portugal. As their European influence began to come under threat from the Romans and Saxons, many migrated to Britain around 500 BCE. Despite invasions from the Romans, Angles, Saxons, Jutes and Vikings, the Celts still remained established inhabitants in many areas of Britain by the 8th century. However, their lands were now pushed back to Wales and Scotland rather than England, which was primarily Anglo-Saxon territory. Their influence can still be seen today with the uncovering of the Tal-y-Llyn hoard of Iron Age metal tools and weapons and substantial evidence of Celtic hill forts in Maiden Castle and Old Oswestry.

The remains of the Celtic hill fort at Maiden Castle

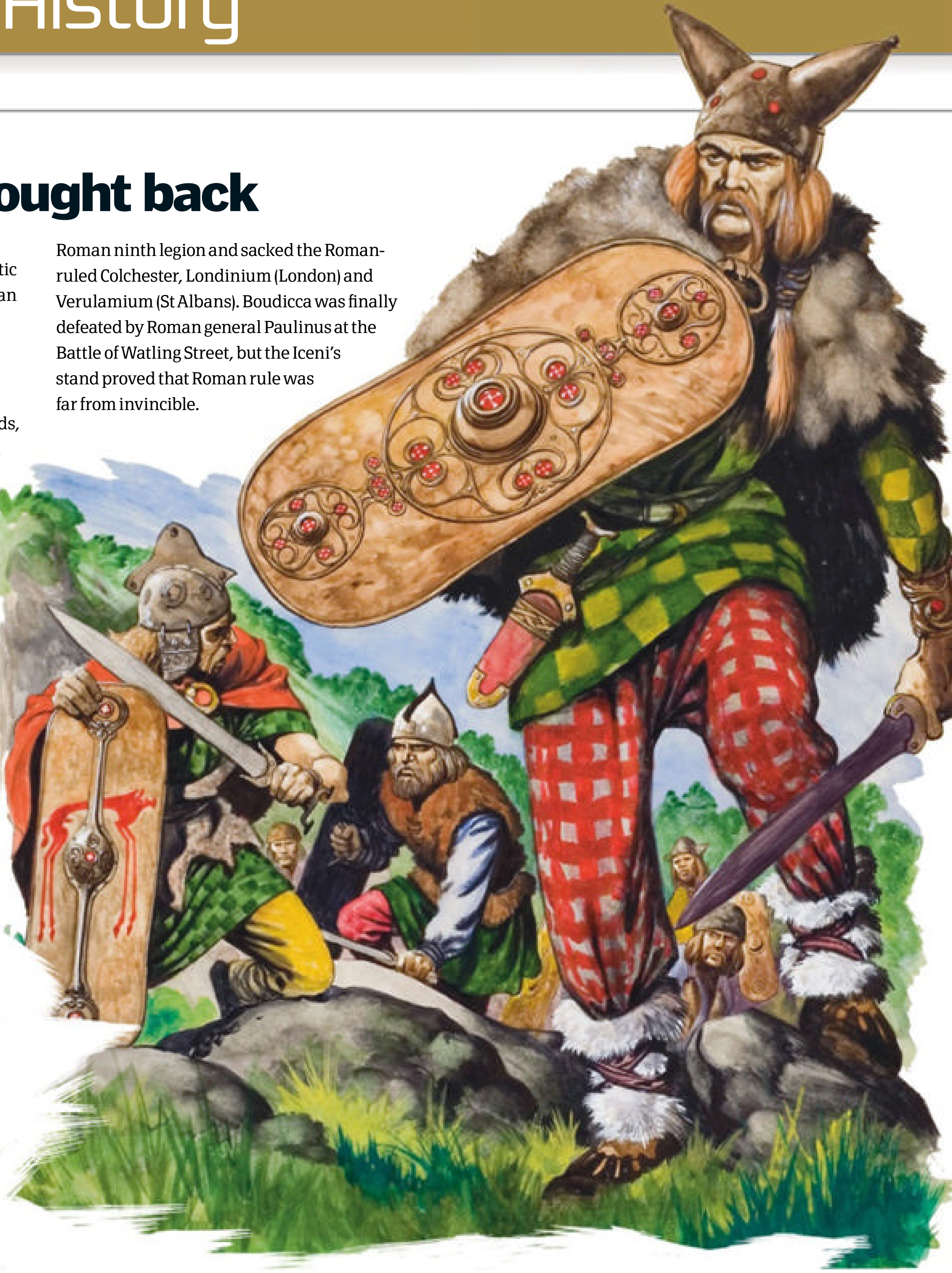
How the Celts fought back

The Celts had a reputation for being fearsome warriors, but the advent of the Iron Age made Celtic Britain even more resistant to overseas attack than before. The mighty Roman army took three attempts to conquer Britain and continually struggled to rule over large parts of the island, especially in Scotland and Wales. The Celts had access to the technology to make their own swords, spears and axes, as well as shields for protection. According to both Greek and Roman historians, the Celts would often go into battle without armour or even completely naked, covered only in war paint. Although there is some evidence that they used helmets and body armour, these were apparently rare, possibly only used by chieftains and high-ranking warriors.

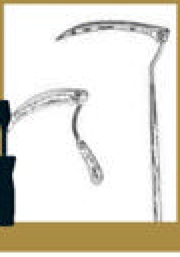
The Celtic military was primarily based around infantry, but they also used chariots and – occasionally – cavalry during battles. Their tactics weren't as advanced as the Roman testudo, for instance, but they still had some bold strategies up their sleeve.

The most famous is perhaps the Furor Celtica. Translated to 'Celtic Fury', it was a mass charge on the front of an enemy line that was used to disrupt and split enemy ranks. Celts on the continent were known to be more defensive and used a tight phalanx set-up, much like the original Greek formation.

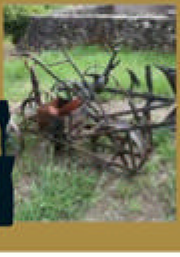
The Celtic tribes had many iconic chieftains such as Vercingetorix, Caratacus and Cassivellaunus, but the most famous, without a doubt, was Boudicca (or Boadicea). The fierce and influential warrior queen of the Iceni tribe, she led a resistance force against the Roman invaders. Successfully forming an alliance with various other clans around the British Isles, her forces defeated the Roman ninth legion and sacked the Roman-ruled Colchester, Londinium (London) and Verulamium (St Albans). Boudicca was finally defeated by Roman general Paulinus at the Battle of Watling Street, but the Iceni's stand proved that Roman rule was far from invincible.



What tools and weapons did the Celts use?



Sickles & scythes
Used to cut crops and chop wood, iron scythes and sickles made farming and building simpler and quicker.



Ploughs
The 'ard' broke up fertile soil for crops so large communities could be fed, a big reason for the Iron Age population increase.

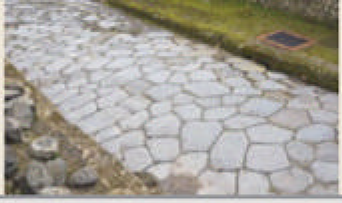
Spears
The advent of iron smelting brought tougher and sharper spears. These helped in hunting large game and were also used in warfare.

Helmets
The Celts donned two types of helmet: the Montefortino and the Coolus. The latter was the legionnaires' helmet of choice.

STRANGE BUT TRUE
ON THE ROAD AGAIN

Who invented the first European road network?

A The Celts **B** The Romans **C** The Aztecs



Answer:
The Romans are often attributed with creating the infrastructure of Europe but recent research has shown the Celts may have preceded them. Not as long lasting or well built, Celtic roads such as the Via Heraclea still provided a transport system.

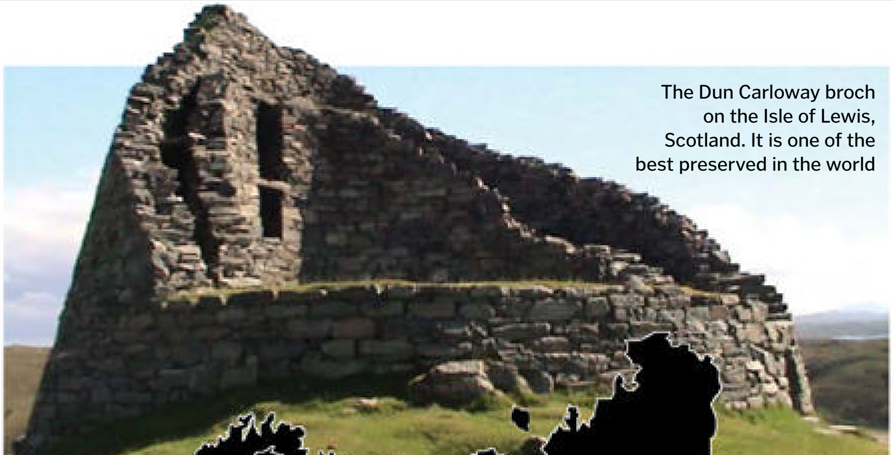
DID YOU KNOW? *The Celts didn't have a writing system, so much of what we know comes from artwork and secondary accounts*

There were other types of settlements

Hill forts were the most common type of settlement in Celtic Britain, but there were other types of communities too. In Scotland, for instance, brochs were very common. Stone was more readily available than wood in the north so hollow dry stone towers were built. A structure known as a crannog was also popular on the side of the lochs of Scotland.

Hill forts themselves also differed across the British Isles. Where the terrain was not hilly, a plateau or valley fort had to rely on man-made defences for protection. Others were built on river confluences for water access while others were purposely constructed on coastlines. Last of all, some forts were not built with defence as a priority so had smaller walls and enclosures.

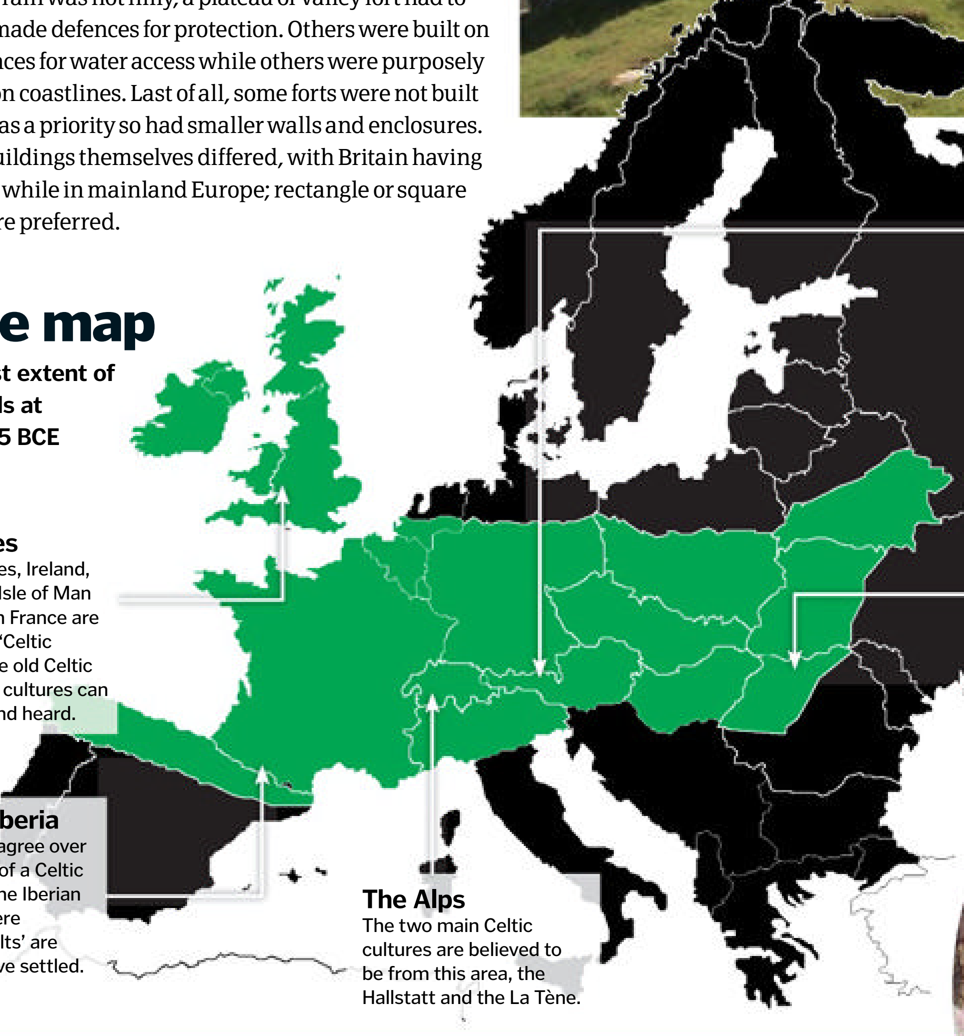
Even the buildings themselves differed, with Britain having roundhouses while in mainland Europe; rectangle or square buildings were preferred.



The Dun Carloway broch on the Isle of Lewis, Scotland. It is one of the best preserved in the world

On the map

🟩 **The largest extent of Celtic lands at around 275 BCE**



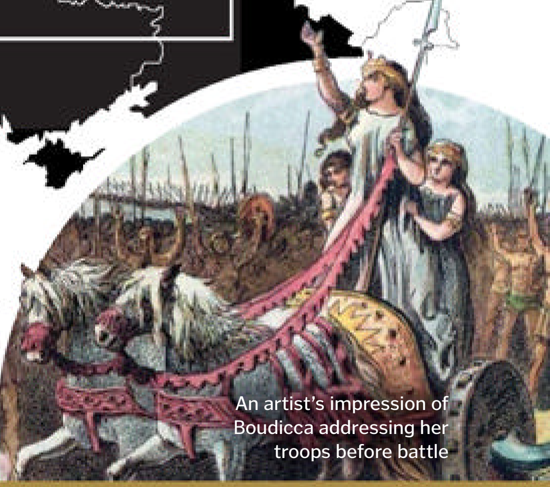
Place of origin
The Celts originated in an area known as 'Hallstatt' in the foothills of the Alps in modern-day Austria.

East expansion
The extent of Celtic expansion reached as far east as parts of Romania by 275 BCE before the rise of the Roman Empire.

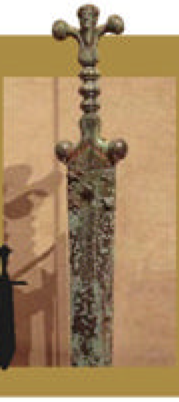
British Isles
Scotland, Wales, Ireland, Cornwall, the Isle of Man and Brittany in France are known as the 'Celtic Nations' where old Celtic traditions and cultures can still be seen and heard.

Gaul and Iberia
Historians disagree over the likelihood of a Celtic presence on the Iberian Peninsula where 'Lusitanian Celts' are thought to have settled.

The Alps
The two main Celtic cultures are believed to be from this area, the Hallstatt and the La Tène.



An artist's impression of Boudicca addressing her troops before battle



Longer swords
As iron and steel production techniques gradually improved, longer, double-edged and better balanced swords became a popular weapon of choice in Celtic warfare.

Falcata sword
A typical Celtic sword used in the Iberian Peninsula. A short sword used for quick slashes, it delivered a powerful blow and could split enemy shields and helmets.

Armour
Known as Ceannlann, it was a mixture of linen and metal scales sewn onto chain mail armour. Nobles and rich Celts could afford this, while poor warriors wore leather armour or none at all.

Ranged weapons
The Celtic infantry focused on close-quarters combat, but after witnessing Viking bows, they began to occasionally use slings, bows and spears for attacks from a distance.

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BUILDINGS, PLACES & LANDMARKS

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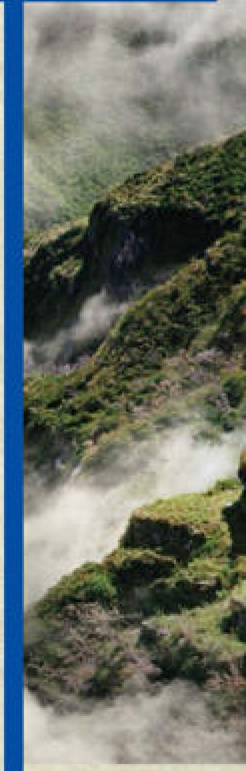
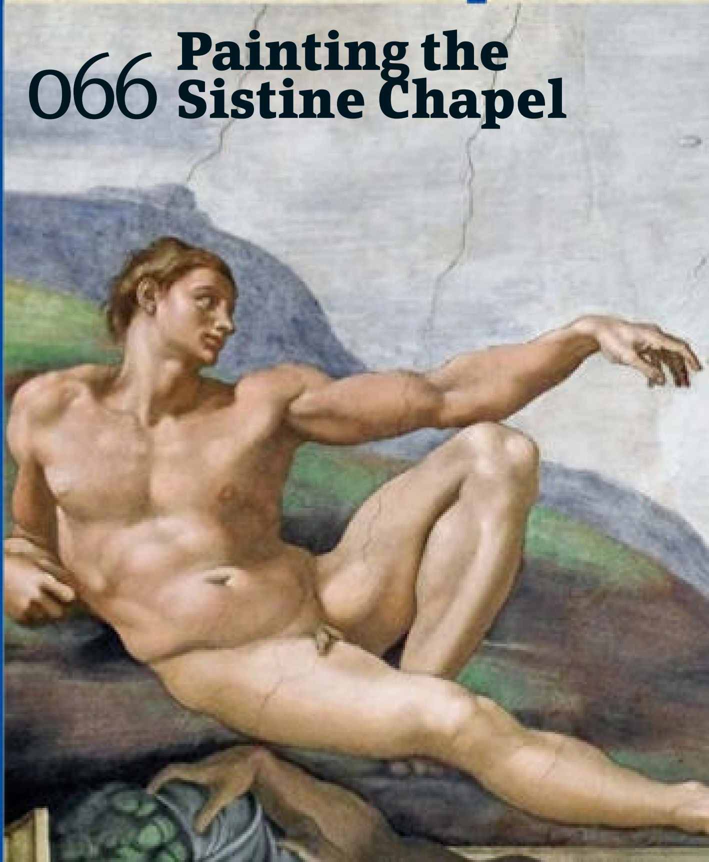
Explore the Welsh captial's central castle




066 Painting the Sistine Chapel

Inside Buckingham Palace 050

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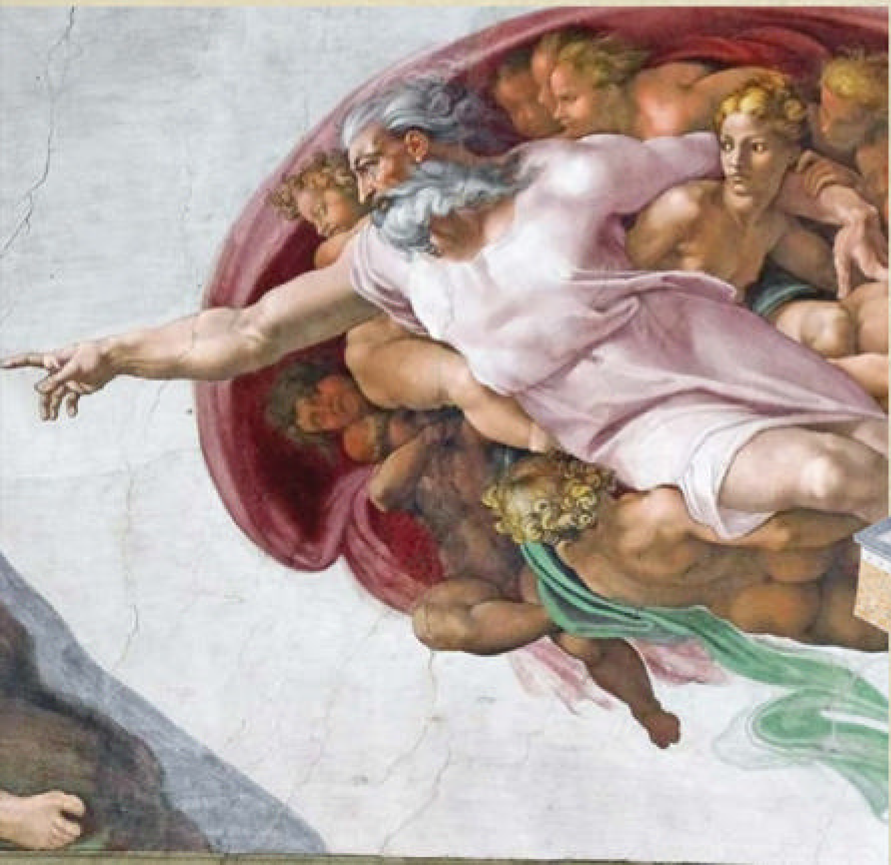
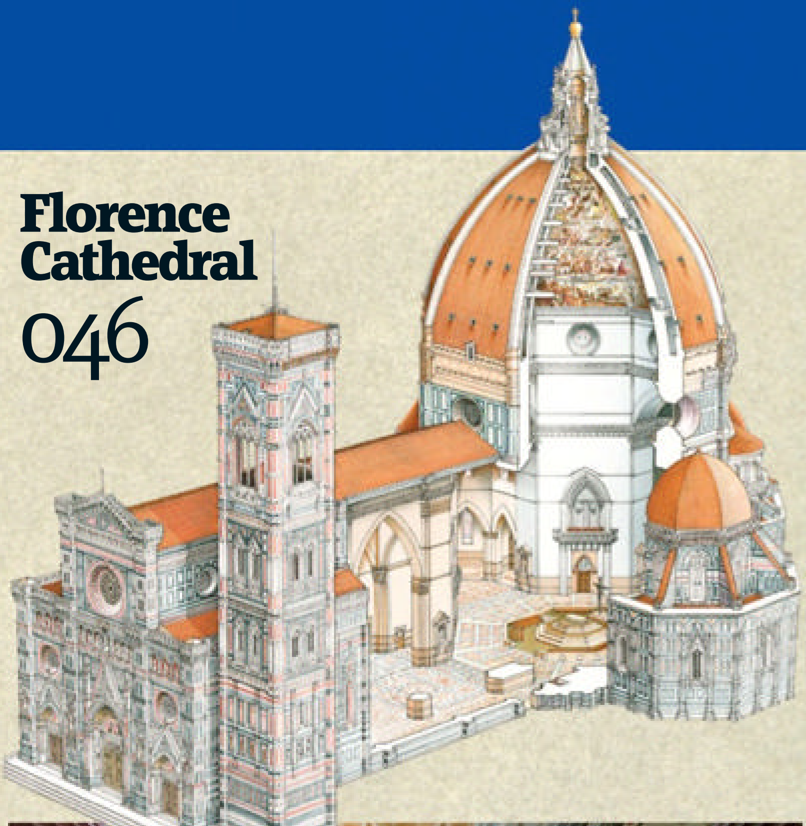
Exploring Macchu Picchu





Florence Cathedral
046

Sagrada Familia
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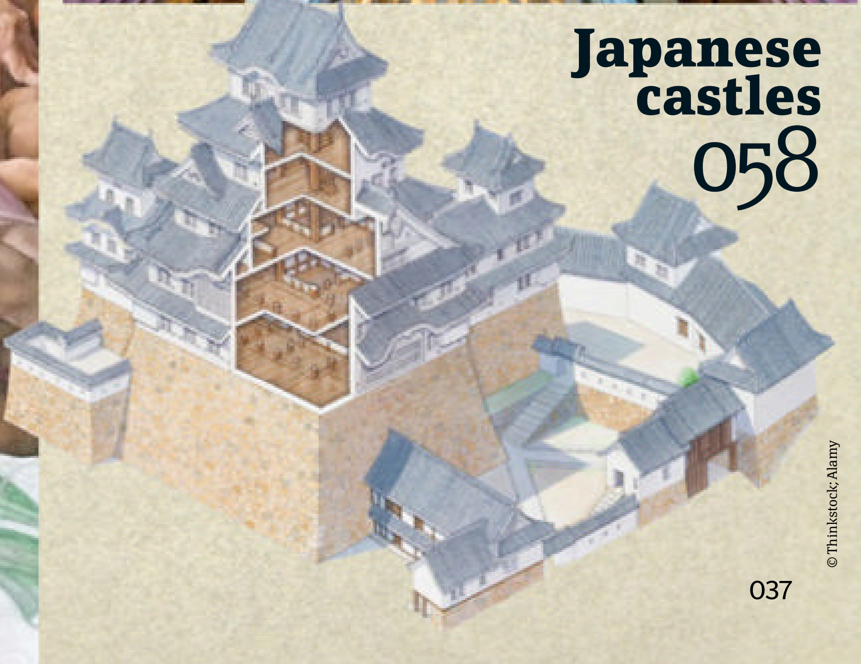

Japanese castles
058

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Saint Mark's Basilica

Why does Venice's most storied and famous church have so much treasure within its walls?

An eye-catching mix of Eastern Byzantine, Western Gothic and even Islamic styles of architecture and art, Saint Mark's Basilica in Venice, Italy is testament not just to the wealth and power of the Medieval Republic of Venice in northeastern Italy, but to its swashbuckling adventures in the Mediterranean – not just as traders, but as conquerors.

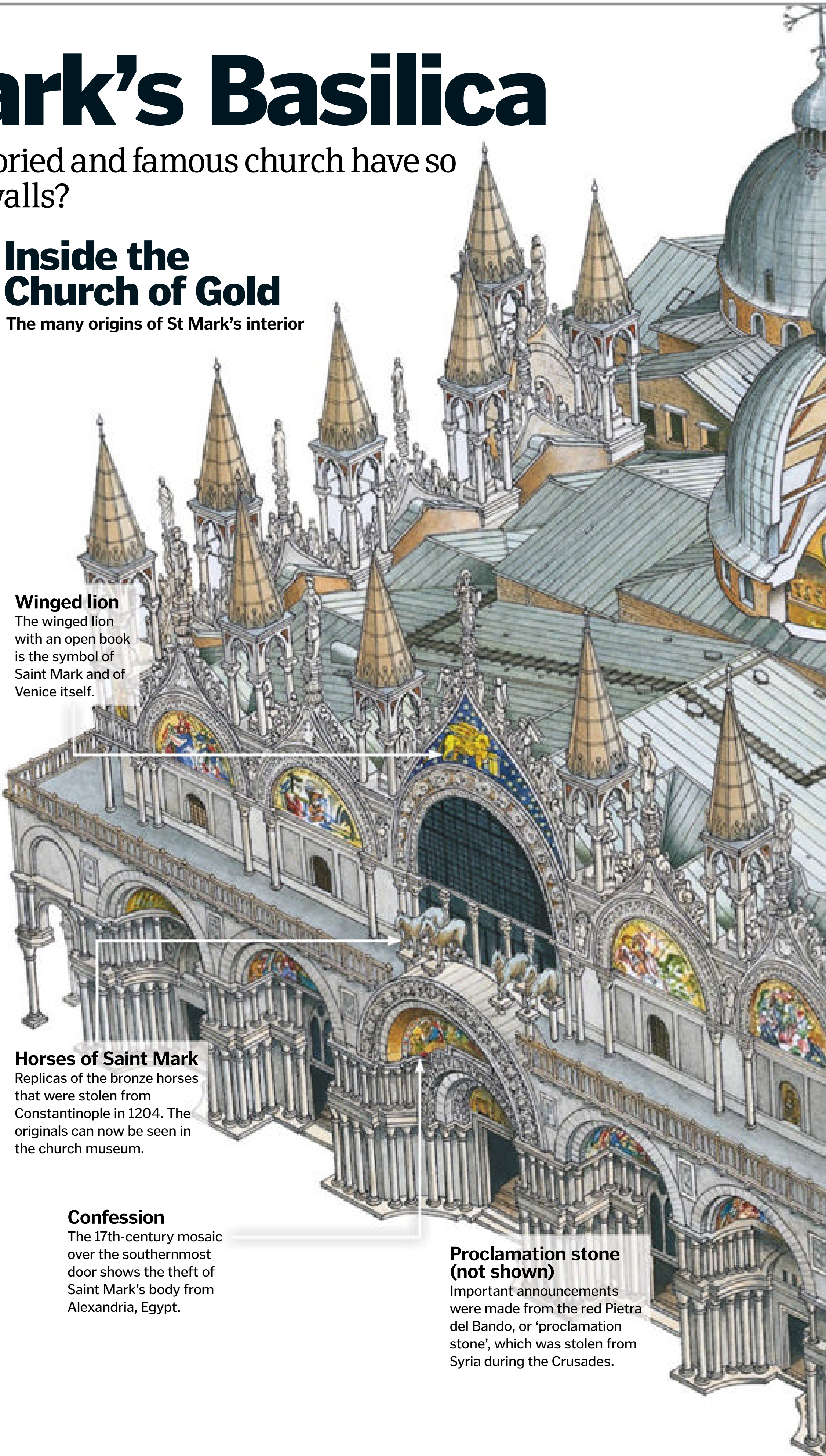
In 828, two rather unscrupulous Venetian merchants stole what they believed were the remains of Saint Mark the Evangelist from Alexandria in Egypt. Declaring Saint Mark their home city's patron saint, they then built a church to house the body. Instead of hiding its origin, one mosaic in Saint Mark's Basilica even boasts of the theft – showing the Venetians in question hiding the stolen saint in barrels of pork, which the Muslim Egyptians were forbidden from touching, so that the customs officials wouldn't inspect their cargo too closely.

After the original church was damaged in a fire in 976, it was restored and then rebuilt some time before 1094 around the striking central dome that still stands there today. With Venice at the height of its powers in the 11th to 14th centuries, the city provided naval support to European armies in the Crusades and actually led the Fourth Crusade against Constantinople (now Istanbul in Turkey, but then the Greek Orthodox Christian capital of the Byzantine Empire) and took the opportunity to loot its many religious relics, gold and chalices, as well as four bronze horse statues, to further embellish their Basilica. The Venetians even stole mosaics, columns and carvings from various churches and houses of worship across the Middle East to pile onto their own back in Venice.

Not everything that found its way into the Basilica was taken by force, though, for it was also a tradition for Venetian merchants to bring back gifts from their travels, making Saint Mark's Basilica – or to give it its 11th-century nickname, Chiesa d'Oro, or 'Church of Gold' – one of the most beautiful cathedrals in not only Italy, but all of Europe.

Inside the Church of Gold

The many origins of St Mark's interior



Winged lion
The winged lion with an open book is the symbol of Saint Mark and of Venice itself.

Horses of Saint Mark
Replicas of the bronze horses that were stolen from Constantinople in 1204. The originals can now be seen in the church museum.

Confession
The 17th-century mosaic over the southernmost door shows the theft of Saint Mark's body from Alexandria, Egypt.

Proclamation stone (not shown)
Important announcements were made from the red Pietra del Bando, or 'proclamation stone', which was stolen from Syria during the Crusades.

KEY DATES
ST MARK'S STORY

832
The original Saint Mark's Basilica is constructed to house the saint's pilfered remains.

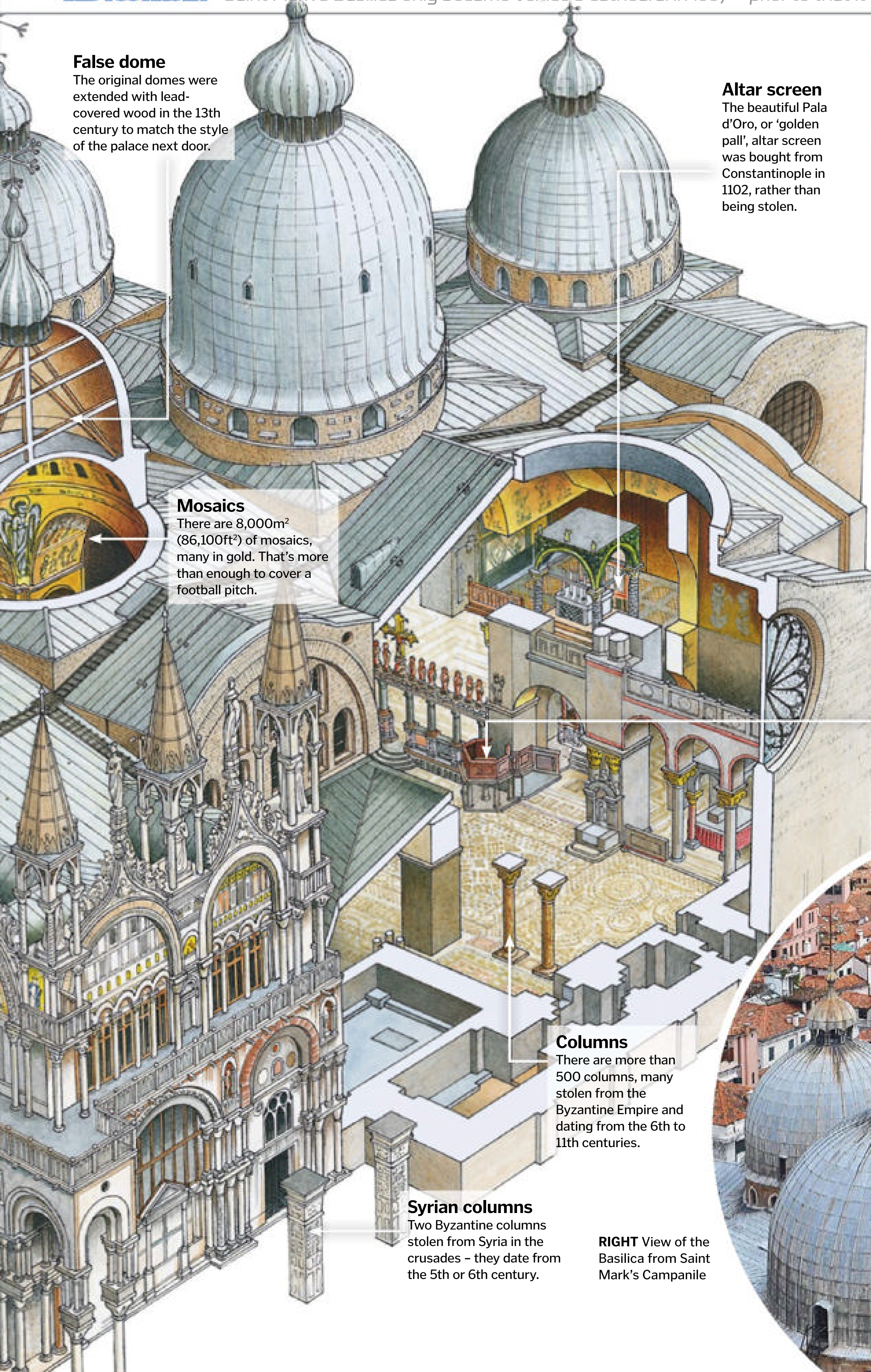
976
The Basilica is damaged by a fire during a revolution against Venice's ruler Pietro IV Candiano.

1094
The new church is consecrated. It will be modified many times over the coming centuries.

1202
Venice leads the Fourth Crusade against Constantinople; Saint Mark's is showered in booty.

1797
Napoleon Bonaparte steals many treasures from Saint Mark's. Most are later returned.

DID YOU KNOW? *Saint Mark's Basilica only became Venice's cathedral in 1807 – prior to that it was a chapel*



False dome
The original domes were extended with lead-covered wood in the 13th century to match the style of the palace next door.

Altar screen
The beautiful Pala d'Oro, or 'golden pall', altar screen was bought from Constantinople in 1102, rather than being stolen.

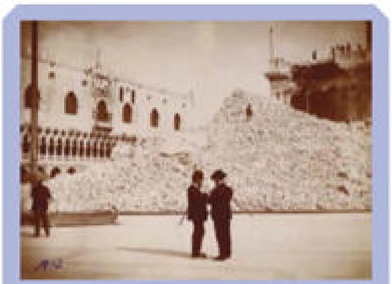
Mosaics
There are 8,000m² (86,100ft²) of mosaics, many in gold. That's more than enough to cover a football pitch.

Doge's platform
To the left of the altar is a platform where Venice's ruler, the doge, would appear after his election.

Columns
There are more than 500 columns, many stolen from the Byzantine Empire and dating from the 6th to 11th centuries.

Syrian columns
Two Byzantine columns stolen from Syria in the crusades – they date from the 5th or 6th century.

© DK



The falling tower
Italian churches often have bell towers, or 'campaniles', separate from the main building and Saint Mark's Campanile, which stands 50m (164ft) high, was built in the 9th century. The tower is so iconic that not only does it adorn postcards, magnets and T-shirts, but replicas – most often used as clock towers – can be found around the world.

But even Saint Mark's Campanile itself is something of a replica. In the early hours of 14 July 1902 a crack appeared in the wall, which continued to grow. Then at 9.45am, the tower completely collapsed. It was rebuilt with stronger foundations and finally opened on 25 April 1912. The reconstruction cost 2.2mn lire (£88,000), a vast amount at the time.

RIGHT View of the Basilica from Saint Mark's Campanile

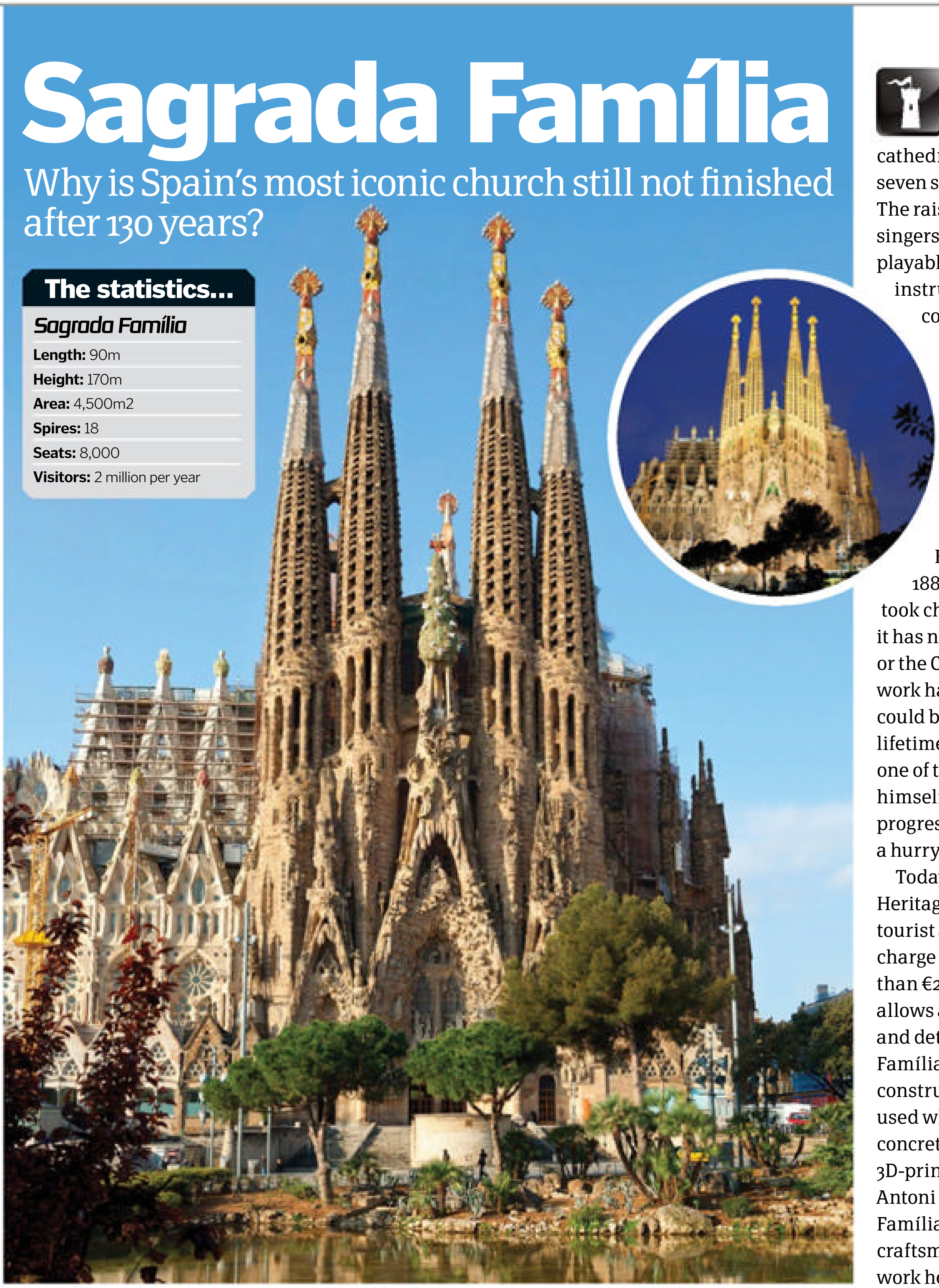
Sagrada Família

Why is Spain's most iconic church still not finished after 130 years?

The statistics…

Sagrada Família

Length: 90m
Height: 170m
Area: 4,500m2
Spires: 18
Seats: 8,000
Visitors: 2 million per year



Sagrada Família is not a cathedral, because it doesn't have a bishop. But it was intended from the outset to be cathedral *sized*. The design calls for 18 spires, seven side chapels and three grand facades. The raised choir space has room for 1,100 singers and the six separate organs will be playable from a central console to give a single instrument with 8,000 pipes. When it is completed, Sagrada Família will be the tallest church building in the world. But the extraordinary gingerbread architecture has divided opinion from the very beginning. George Orwell called it "one of the most hideous buildings in the world."

The church was commissioned by a pious bookseller called Josep Maria Bocabella and the first stone was laid in 1882. The Spanish architect Antoni Gaudí took charge of the design a year later. Because it has never received money from government or the Catholic Church, the pace of building work has always depended on the money that could be raised privately. During Gaudí's lifetime only the crypt, the apse above it and one of the spires had been completed. Gaudí himself was not concerned with the slow progress and famously said: "My client is not in a hurry."

Today, Sagrada Família is a UNESCO World Heritage Site and one of the most popular tourist attractions in Spain. The admission charge and other fund raising generates more than €25 million (£20 million), which now allows an extraordinary level of craftsmanship and detail on the construction. But Sagrada Família is not a museum piece. Modern construction techniques and materials are used wherever possible, including reinforced concrete, computer-aided design and 3D-printing of plaster decorations. Even though Antoni Gaudí lies buried in the crypt at Sagrada Família, a team of engineers, artists and craftsmen remain dedicated to finishing the work he began.

Construction ahead

The road toward completion of the Sagrada Família has been long and arduous – and there is still some way to go…

1882

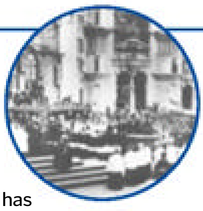
Work begins under the architect Francisco de Paula del Villar y Lozano. It is originally designed as a Gothic revival church.

1883

Gaudí takes over after the original architect disagrees with the project promoter and resigns.

1894

More than a decade later, the crypt and apse (the semi-circular area behind the altar) are the first parts of the church to be finished.



1926

Gaudí dies, aged 74. He has spent over 42 years working on Sagrada Família, but more than 75 per cent of it is still unbuilt.

HEAD 2 HEAD
DELAYED CONSTRUCTIONS

1. LONG

Ryugyong Hotel, North Korea
Begun in 1987, it took 20 years to finish the exterior of this 105-storey hotel and it still hasn't opened.

2. LONGER

Ajuda National Palace, Portugal
The official residence of the Portuguese royal family was begun in 1796 but wars and a revolution stalled construction indefinitely.

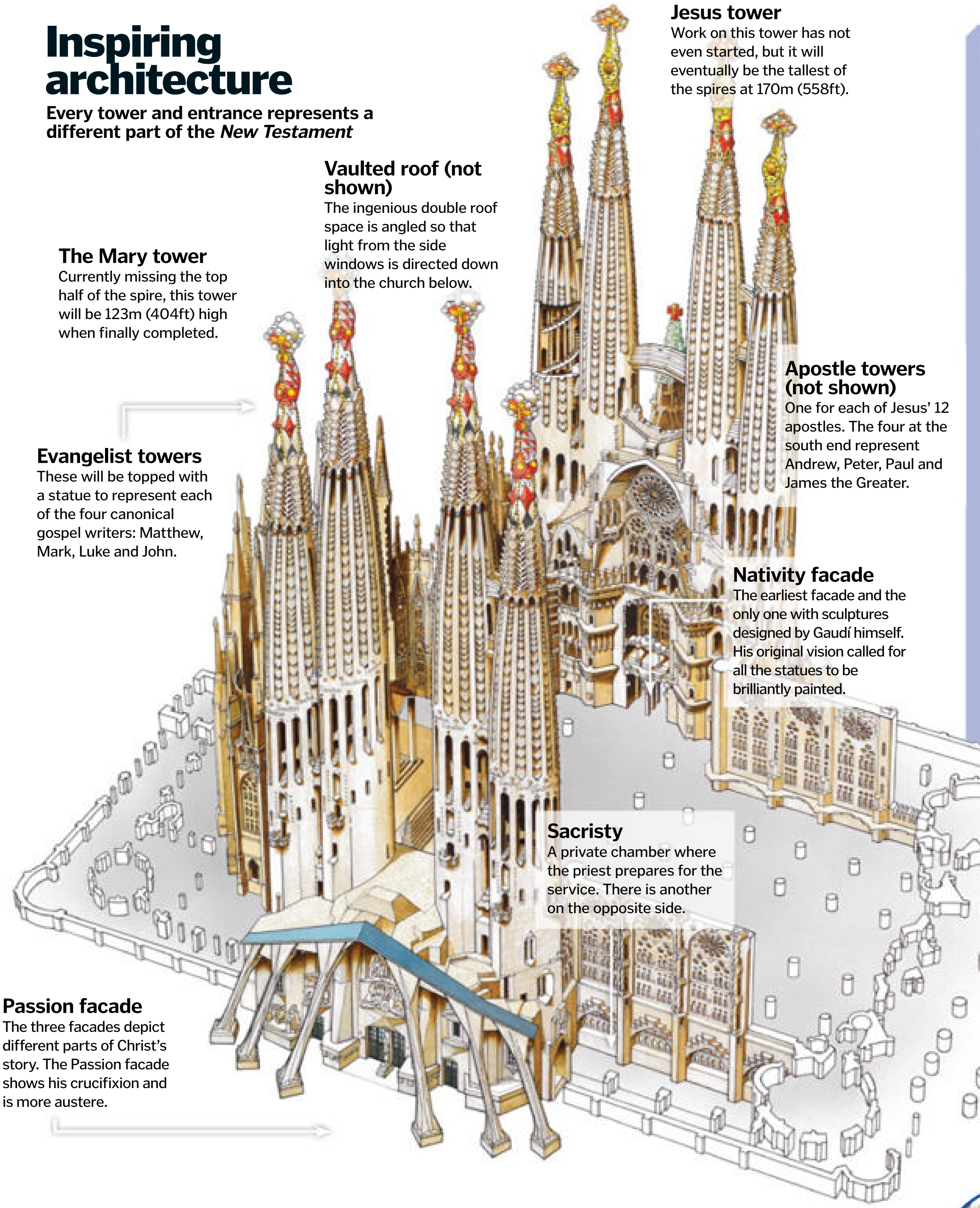
3. LONGEST

Siena Cathedral, Italy
A massive extension to this ancient cathedral was commenced in 1339 but was halted by the Black Death and never finished.

DID YOU KNOW? *The Jesus tower will be 1m (3.3ft) lower than Montjuïc Hill – Gaudí believed his creation should not exceed God's*

Inspiring architecture

Every tower and entrance represents a different part of the *New Testament*



Jesus tower
Work on this tower has not even started, but it will eventually be the tallest of the spires at 170m (558ft).

Vaulted roof (not shown)
The ingenious double roof space is angled so that light from the side windows is directed down into the church below.

The Mary tower
Currently missing the top half of the spire, this tower will be 123m (404ft) high when finally completed.

Evangelist towers
These will be topped with a statue to represent each of the four canonical gospel writers: Matthew, Mark, Luke and John.

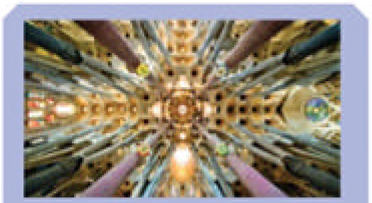
Apostle towers (not shown)
One for each of Jesus' 12 apostles. The four at the south end represent Andrew, Peter, Paul and James the Greater.

Nativity facade
The earliest facade and the only one with sculptures designed by Gaudí himself. His original vision called for all the statues to be brilliantly painted.

Sacristy
A private chamber where the priest prepares for the service. There is another on the opposite side.

Gloria facade
Construction of this facade only began in 2002. It represents humanity's ascension to heaven and will eventually be the grandest of the three facades.

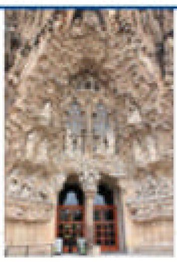
Passion facade
The three facades depict different parts of Christ's story. The Passion facade shows his crucifixion and is more austere.



Modern interior

Sagrada Família uses elaborate branching internal columns to direct all the weight of the building downward. This allows it to have a durable stone roof, instead of the traditional wooden design, and avoids the need for flying buttresses (which Gaudí called 'crutches') to prop up the walls on the outside. The shapes of the columns are modelled on twisting plant stems. At their base, each column begins as a polygon or star, and the number of sides or points doubles at intervals as the columns rise, until they all become cylinders at the top. The stained glass windows are another deliberate departure from traditional Catholic church design. Normally, the panes at the bottom are in lighter colours than those near the top, to give even illumination. At Sagrada Família it's the other way around. The windows at the top of the central nave are completely clear, to flood the vaults with light.

1933
The Nativity facade is finished. It is intended to set the standard for the structure and decoration of the rest of the church.



1936
The Civil War interrupts construction. Catalan anarchists burn down Gaudí's workshop. His models are destroyed.

1978
The four towers of the Passion facade are built and work starts on the facade itself.

1992
The Barcelona Olympics speed up funding by bringing in millions of extra tourists to the city.

2010
The roof of the central nave is completed and Pope Benedict XVI consecrates the basilica so it can be used for religious services at last.

2026
The aim is to have the church completed in time for the centenary of Gaudí's death – 144 years after work began.

© Getty; Alamy

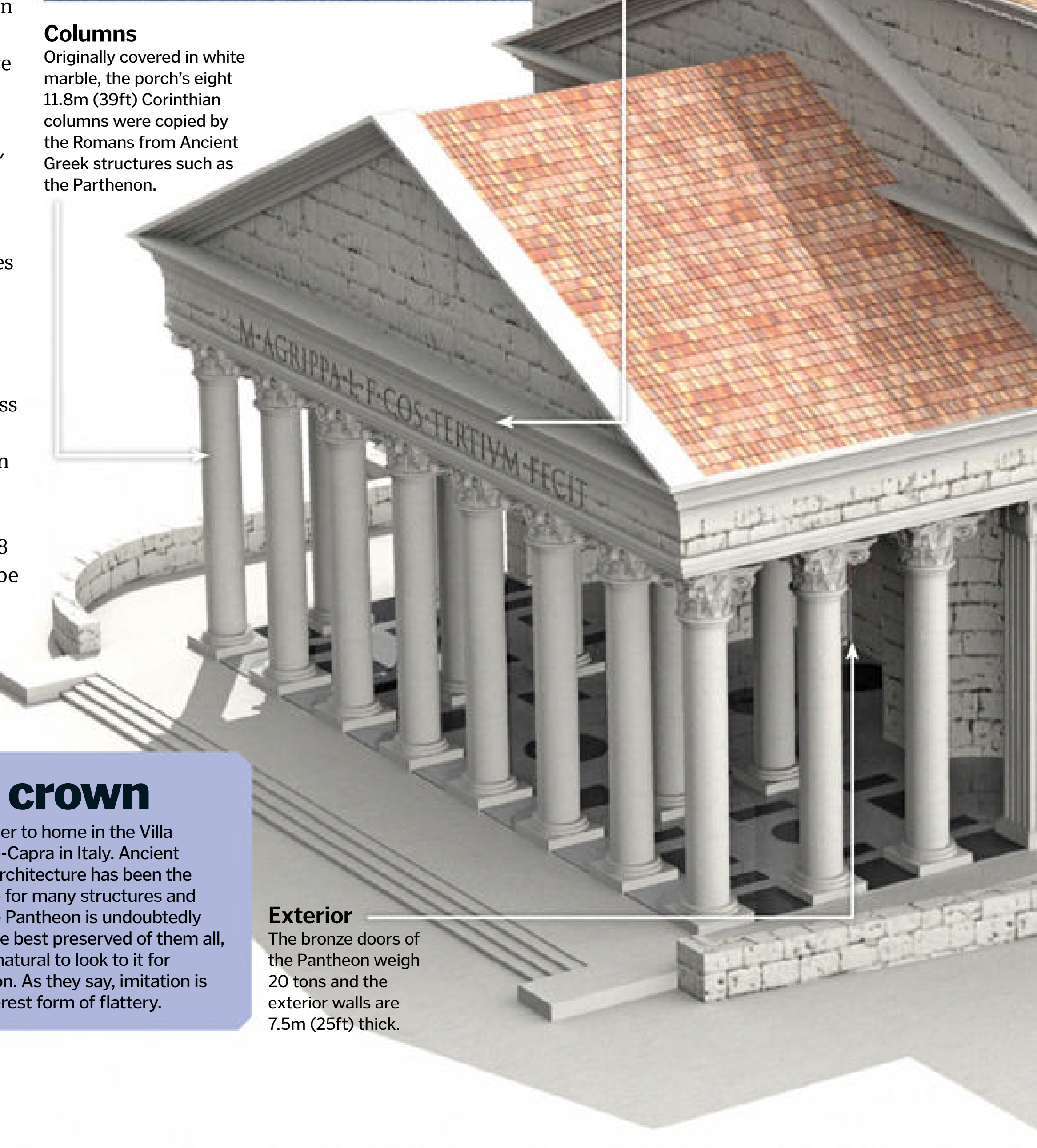
The Pantheon

Bask in the brilliance of Roman architecture

You may have heard of the Roman Emperor Hadrian – he has a wall named after him in Northern England – but his most famous and influential project is the Pantheon. Nestled in the heart of Ancient Rome, it is the largest unreinforced concrete dome in the world. It was completed in around 125 CE after the original was burnt to a cinder. The Pantheon served as both a temple to the gods and also as a place where the emperor could make public appearances.

The front of the structure is Greek in style and is not too different from many of the buildings in Ancient Athens in its pomp. The remainder is a classical Roman style and contains an 8.8-metre (29-foot) oculus in the dome. This opening allowed the Sun to light the main chamber. While the Greek columns were made of marble, the Roman arches inside are constructed from brick. The vast dome is held up by internal arches and step rings and signifies a major breakthrough in architecture. These techniques enabled the Romans to construct the biggest structures ever seen in that period.

With the fall of the Western Roman Empire, Europe experienced a period of architectural decline known as the Dark Ages. As cities across the empire were ransacked, many of the great Roman buildings were destroyed by barbarian hordes. One of the exceptions to this was the Pantheon. It was converted to a Christian Church called the St Mary of the Martyrs in 608 CE. Christianity was the main religion of Europe at the time so this is probably what saved it from being levelled. Currently, the building serves as a symbolic tomb for the old Italian monarchy and as a constant reminder of the greatness of Ancient Rome.



Facade
The writing on the front façade reads: "M Agrippa LF. Cos Tertium Fecit" ("Marcus Agrippa, son of Lucius, three-time consul, made this").

Columns
Originally covered in white marble, the porch's eight 11.8m (39ft) Corinthian columns were copied by the Romans from Ancient Greek structures such as the Parthenon.

Exterior
The bronze doors of the Pantheon weigh 20 tons and the exterior walls are 7.5m (25ft) thick.

Pretenders to the crown

From the Panthéon in Paris to the Pantheon of National Revival Heroes in Bulgaria, the legendary structure has influenced building style around the world. You'll notice the symmetrical design with rows of Corinthian columns reproduced in the US Capitol Building and the Jefferson Memorial in Washington, USA, and a little closer to home in the Villa Almerico-Capra in Italy. Ancient Roman architecture has been the template for many structures and since the Pantheon is undoubtedly one of the best preserved of them all, it's only natural to look to it for inspiration. As they say, imitation is the sincerest form of flattery.

HEAD 2 HEAD
BIGGEST DOMES IN THE WORLD

1. BIG

Oita Bank Dome
This impressive stadium in Japan played host to three fixtures in the 2002 FIFA World Cup and has a dome of 270m (886ft).

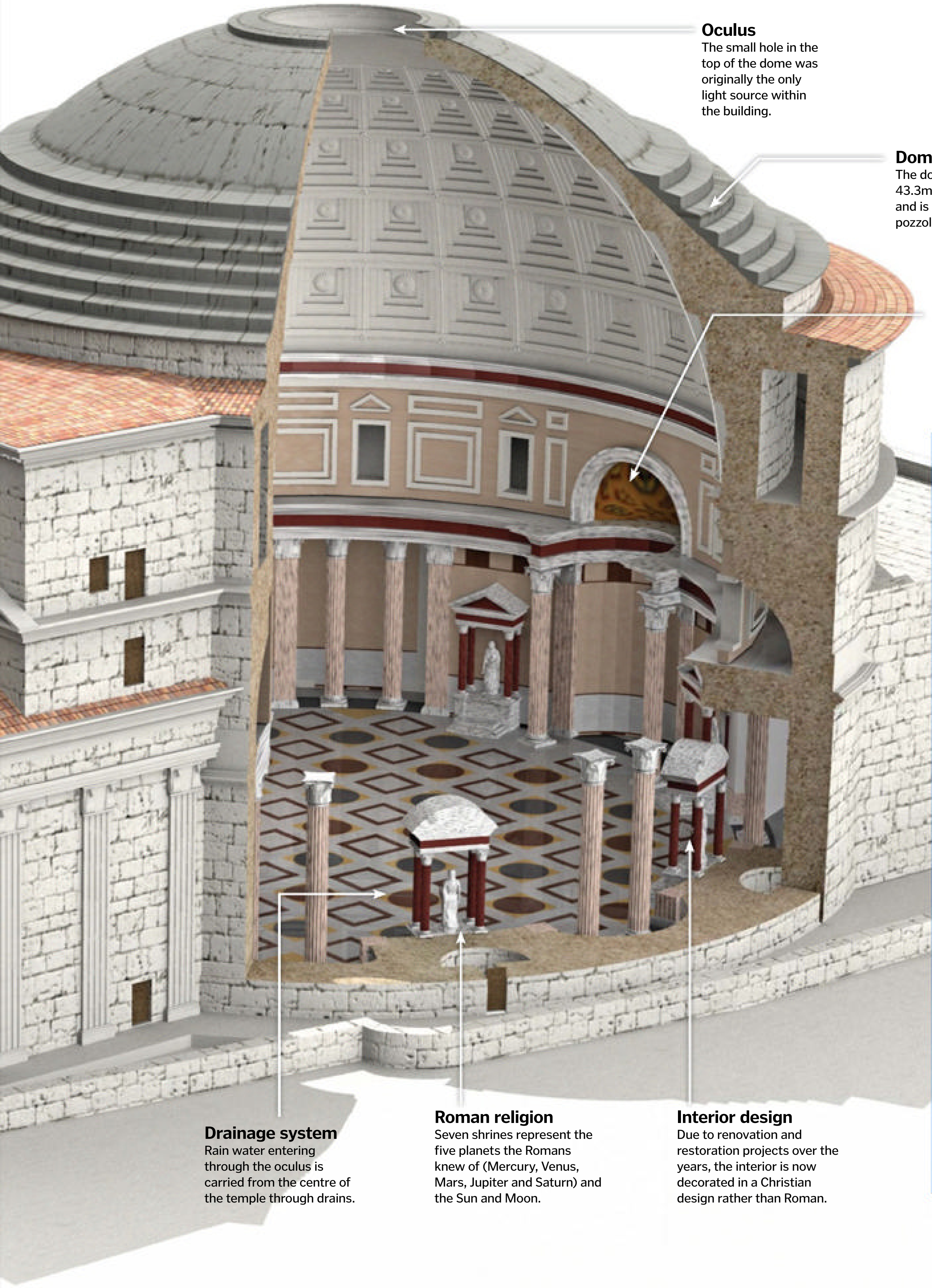
2. BIGGER

AT&T Stadium
The 80,000-capacity home of the NFL's famous Dallas Cowboys, the dome is the biggest in the United States at a huge 274m (900ft).

3. BIGGEST

Singapore National Stadium
At an immense 312m (1,024ft), the retractable roof is the daddy of all domes.

DID YOU KNOW? Every year, on 21 June, the rays of the Sun at the summer equinox shine from the oculus through the front door



Oculus
The small hole in the top of the dome was originally the only light source within the building.

Dome
The dome's rotunda is 43.3m (142ft) in diameter and is constructed from pozzolanic concrete.

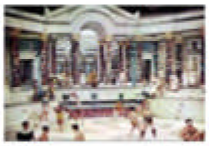
Main room
The main room is designed to symbolise the heavens while the oculus depicts the Sun.

Drainage system
Rain water entering through the oculus is carried from the centre of the temple through drains.

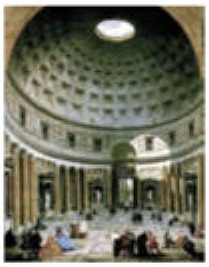
Roman religion
Seven shrines represent the five planets the Romans knew of (Mercury, Venus, Mars, Jupiter and Saturn) and the Sun and Moon.

Interior design
Due to renovation and restoration projects over the years, the interior is now decorated in a Christian design rather than Roman.

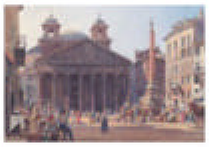
Pantheon through the ages



126 CE
A temple to all the Roman gods



1600
A Renaissance period regeneration



1835
The short-lived bell towers are seen here

2014
Today, it hosts mass and weddings

© Thinkstock, Solyo, Corbis, Alamy

Seville Cathedral

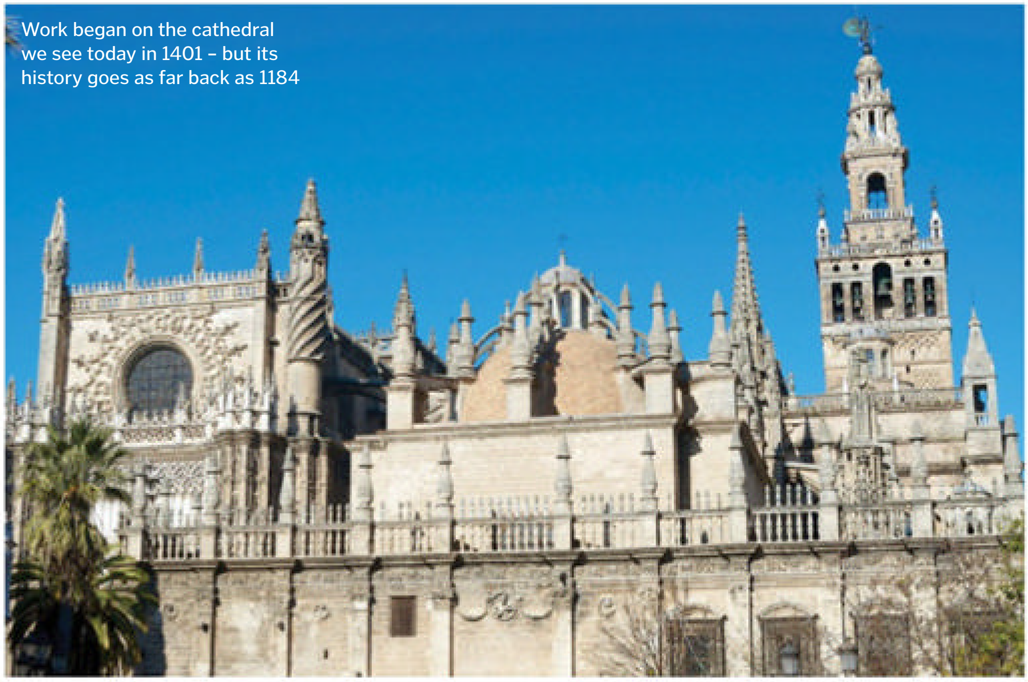
The largest Gothic cathedral in the world, when completed it was regarded as a wonder of its age. It's easy to see why…

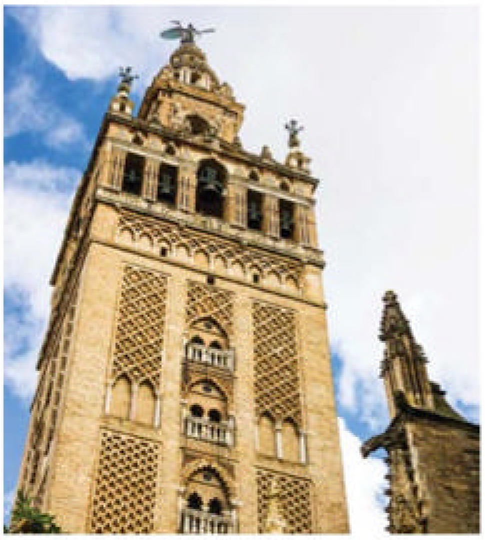
The Cathedral of St Mary of the See, more commonly known as Seville Cathedral, is the mother church of Andalucía. The cathedral was built on the site of a former 12th-century Almohad mosque. This house of prayer originally consisted of a rectangular courtyard, flanked by the mosque itself – a low rectangular building, oriented east to west, containing many aisles divided by long lines of pillars. Built of stone and brick, the mosque had a tall minaret on its eastern flank.

After the Christian conquest of the city in 1248, the mosque was quickly converted into a church – the minaret pressed into use as a bell tower. By the beginning of the 15th century, however, the structure of the old mosque had become so dilapidated that it was decided to build an entirely new cathedral in stone. This new church largely followed the ground plan of its predecessor, but it was considerably taller and contained fewer columns. In result, the cathedral has a vast, hall-like interior.

But despite its massive walls and complex system of flying buttresses, which supported the stone vaults, the new cathedral's design was far from perfect. Structural instability resulted in the collapse of the central tower in 1511, which was then rebuilt to an improved design. However, it again fell down in 1888 – this time due to an earthquake – and its reconstruction didn't take place till 1903.

The cathedral also contains many famous tombs. The most notable is that of the explorer Christopher Columbus, which stands in the south transept. Three kings of Castile are also buried in the cathedral – Pedro I, Alfonso X and St Ferdinand III. Due to its size, architectural importance and the artistic treasures that it houses, Seville Cathedral was designated a UNESCO World Heritage Site in 1987.


Work began on the cathedral we see today in 1401 – but its history goes as far back as 1184



Up close with the iconic giralda

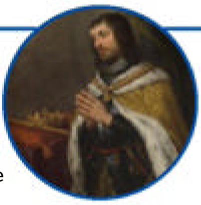
The cathedral's bell tower started life as the minaret of the original mosque of Seville. Constructed between 1184 and 1198, by the architect Ahmed Ben Basso, the brick tower was topped by large decorative gilt bronze spheres. After Seville was taken by the Christians in the 13th century, the minaret was converted into the cathedral's bell tower by the addition of a belfry stage. After an earthquake in the mid-14th century, the Islamic bronze balls collapsed and they were replaced by a large central bell house topped by a cross. This was in turn replaced when the Renaissance architect Hernán Ruiz the Younger designed a new belfry surmounted by a spire topped by a large bronze statue representing the triumph of Christianity. Finally completed in 1568, many architects have since found inspiration in the giralda's design and fusion of architectural styles.

Cathedral in progress

Key events in cathedral history

1184 The building of the original Almohad mosque began.

1248 Seville is conquered by Ferdinand III and the mosque turned into a church.



1401 Work on the present-day cathedral starts.

1507 The main body of the cathedral church is finished.

HEAD 2 HEAD
CATHEDRALS OF THE WORLD

1. LONG

Seville Cathedral

Despite being the largest Gothic cathedral in the world, at 132m (433ft) Seville Cathedral's length is pretty average.

2. LONGER

Liverpool Cathedral

The longest cathedral in Britain, at 188.7m (619ft), Liverpool's 20th-century cathedral is the world's second longest.

3. LONGEST

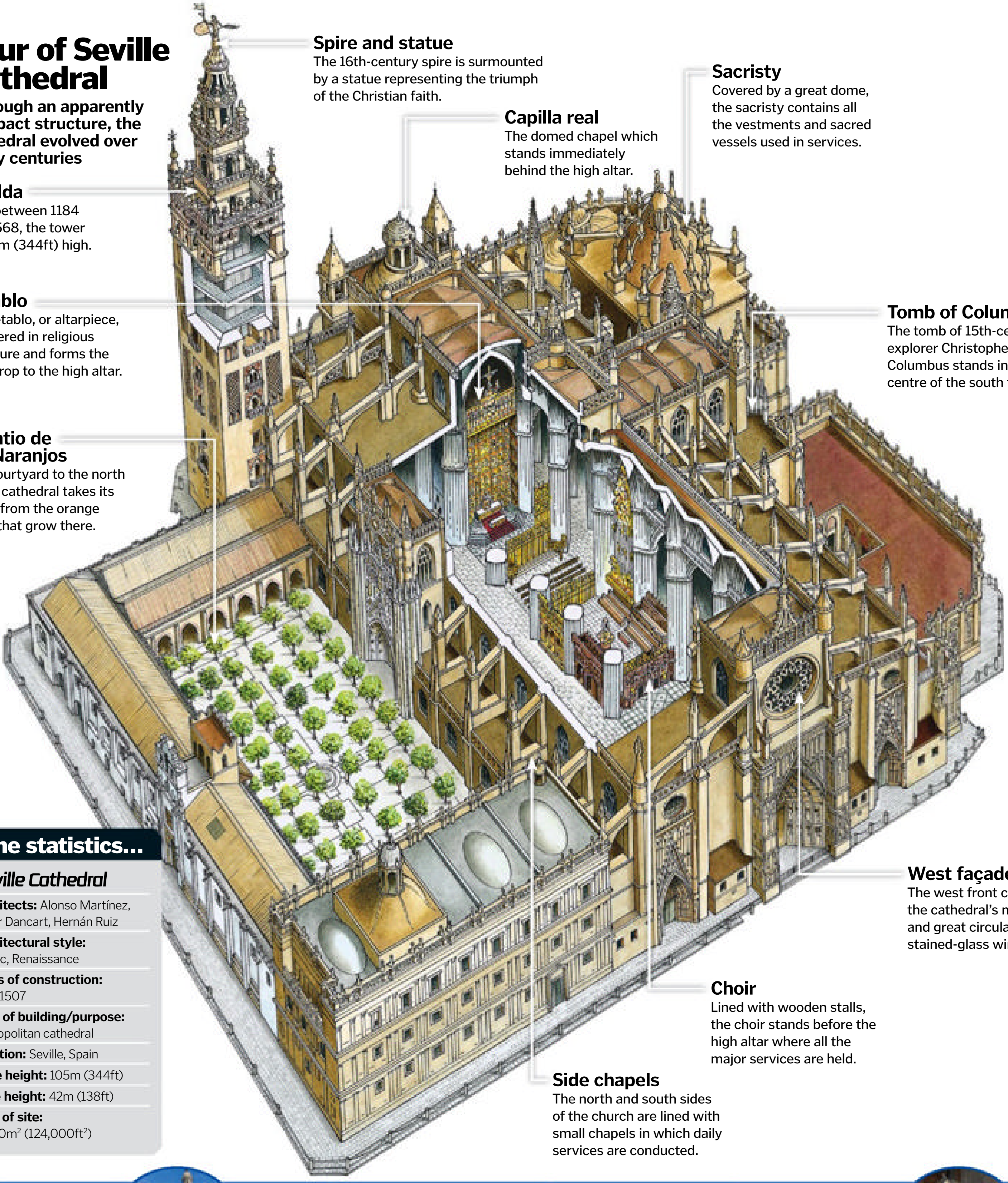
St Peter's Basilica

It may be over 400 years old, but at 211.5m (694ft), St Peter's Basilica in Rome, Italy, is the longest church by a long chalk.

DID YOU KNOW? *In 1401 the cathedral chapter resolved to build a church so large that all who saw it would think they were 'mad'*

Tour of Seville Cathedral

Although an apparently compact structure, the cathedral evolved over many centuries



Giralda
Built between 1184 and 1568, the tower is 105m (344ft) high.

Retablo
The retablo, or altarpiece, is covered in religious sculpture and forms the backdrop to the high altar.

El Patio de los Naranjos
The courtyard to the north of the cathedral takes its name from the orange trees that grow there.

Spire and statue
The 16th-century spire is surmounted by a statue representing the triumph of the Christian faith.

Capilla real
The domed chapel which stands immediately behind the high altar.

Sacristy
Covered by a great dome, the sacristy contains all the vestments and sacred vessels used in services.

Tomb of Columbus
The tomb of 15th-century explorer Christopher Columbus stands in the centre of the south transept.

West façade
The west front contains the cathedral's main door and great circular stained-glass window.

Choir
Lined with wooden stalls, the choir stands before the high altar where all the major services are held.

Side chapels
The north and south sides of the church are lined with small chapels in which daily services are conducted.

The statistics…

Seville Cathedral

Architects: Alonso Martínez, Pieter Dancart, Hernán Ruiz

Architectural style: Gothic, Renaissance

Years of construction: 1401-1507

Type of building/purpose: Metropolitan cathedral

Location: Seville, Spain

Spire height: 105m (344ft)

Nave height: 42m (138ft)

Area of site: 11,520m² (124,000ft²)

1569
The top stages of the bell tower are finished.

1656
The baptistry, with its painting The Vision Of St Anthony, is built.

1888
The cathedral's central tower and vaults collapse.

1898
Christopher Columbus's bones are interred to Seville Cathedral.

© Thinkstock; DK Images; Miguel Mendez; Roberto Chamoso

Italy
Florence
Mediterranean

The statistics...

Florence Cathedral

Height: 114.5m (375ft)
Length: 153m (502ft)
Width: 38m (125ft)
Cost: At least £500m ($802m)
Date of construction: 1296-1436
Architect: At least 11 different architects

Florence Cathedral

Crowned with the largest masonry dome in the world, Florence Duomo is a Renaissance masterpiece

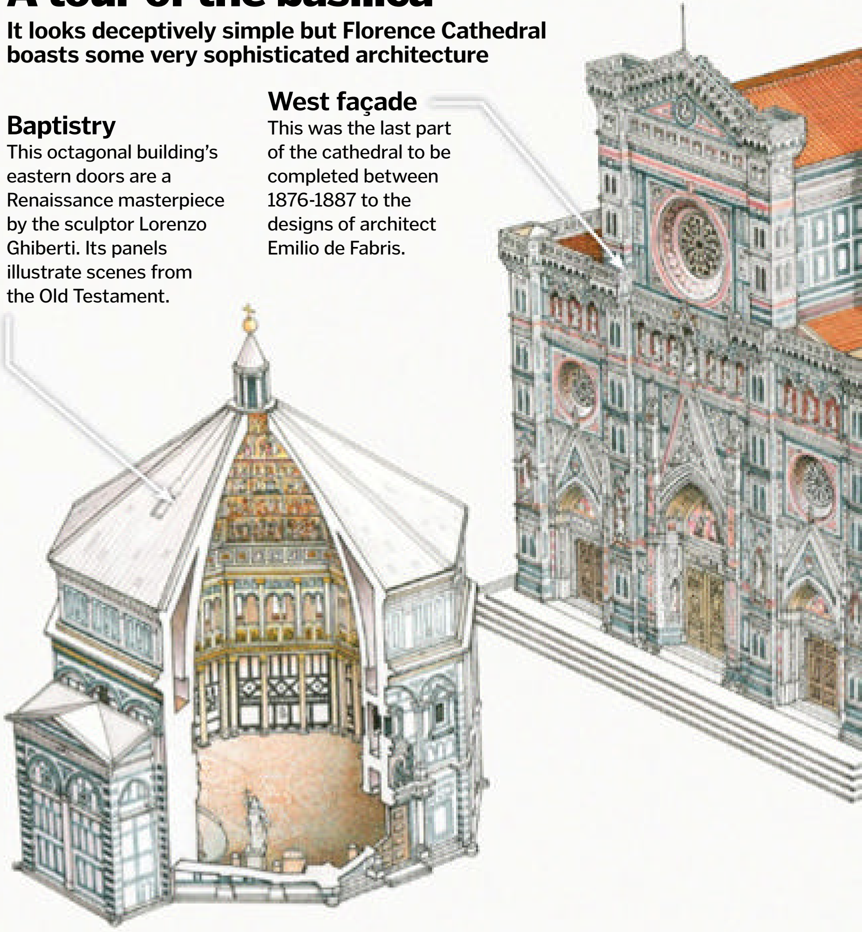
Popularly called the Duomo, Florence Cathedral's name is derived from the Latin 'domus dei' – the House of God – and is dedicated to the Virgin Mary Santa Maria del Fiore (St Mary of the Flower). The present building was started in 1296 and is the third cathedral to stand on the site. Taking 140 years to build, the original plan was only changed once during construction when the eastern half of the cathedral was massively expanded to allow for the now iconic dome. Work on this extraordinary structure began in 1420 and was completed in just 16 years. Higher and wider than any previously built, the octagonal dome was constructed without using a temporary wooden supporting frame. Consisting of a double shell made of sandstone, marble and brick, the base of the dome is 52 metres (171 feet) above the ground and has a staggering 44-metre (144-foot) diameter.

The cathedral's exterior walls are faced in alternate vertical and horizontal bands of coloured marble – white from Carrara, green from Prato and red from Siena. Despite the many architects to work on it the building retains a remarkable architectural and aesthetic cohesion. The interior is sparsely decorated, but contains a number of major Renaissance artworks and 44 stained-glass windows – in fact, the largest expanse of glass installed during 14th and 15th-century Italy.

Above the main door is the basilica's one-handed liturgical clock, which shows all 24 hours. Erected in 1443, it is still working today. The largest cathedral in Europe when it was built, it has become symbolic of Florence and its dome is instantly recognised around the globe. Such is the Duomo's cultural importance that the cathedral complex was designated a UNESCO World Heritage site in 1982.

A tour of the basilica

It looks deceptively simple but Florence Cathedral boasts some very sophisticated architecture



Baptistry
This octagonal building's eastern doors are a Renaissance masterpiece by the sculptor Lorenzo Ghiberti. Its panels illustrate scenes from the Old Testament.

West façade
This was the last part of the cathedral to be completed between 1876-1887 to the designs of architect Emilio de Fabris.

KEY DATES

THE DUOMO

1296
The building of the present cathedral begins to the east of the old cathedral of St Reparata.

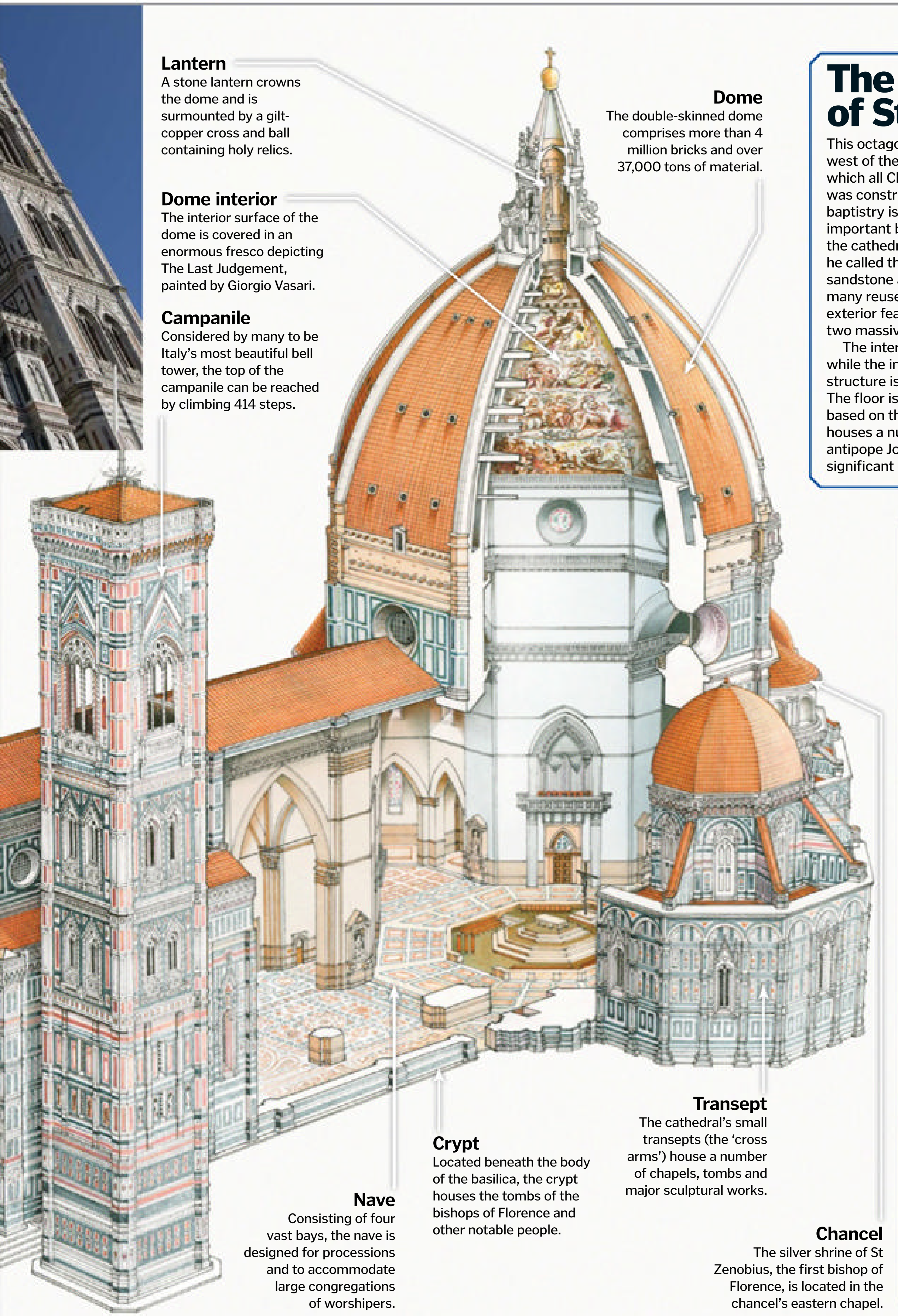
1436
The cathedral is formally consecrated by Pope Eugene IV (right).

1439
The Council of Florence is held to try and reunify the Orthodox and Catholic churches.

1865
Florence is made capital of the newly created Kingdom of Italy; the Duomo is its cathedral.

1887
The cathedral's neogothic west façade is finally completed.

DID YOU KNOW? *The famous English mercenary, Sir John Hawkwood, was buried in Florence Cathedral in 1394*



Lantern
A stone lantern crowns the dome and is surmounted by a gilt-copper cross and ball containing holy relics.

Dome interior
The interior surface of the dome is covered in an enormous fresco depicting The Last Judgement, painted by Giorgio Vasari.

Campanile
Considered by many to be Italy's most beautiful bell tower, the top of the campanile can be reached by climbing 414 steps.

Dome
The double-skinned dome comprises more than 4 million bricks and over 37,000 tons of material.

Nave
Consisting of four vast bays, the nave is designed for processions and to accommodate large congregations of worshipers.

Crypt
Located beneath the body of the basilica, the crypt houses the tombs of the bishops of Florence and other notable people.

Transept
The cathedral's small transepts (the 'cross arms') house a number of chapels, tombs and major sculptural works.

Chancel
The silver shrine of St Zenobius, the first bishop of Florence, is located in the chancel's eastern chapel.

The Baptistry of St John

This octagonal building stands slightly to the west of the cathedral. Built to house the font in which all Christians in Florence were baptised, it was constructed between 1059 and 1128. The baptistry is famous for three sets of artistically important bronze doors. The eastern pair, facing the cathedral, so impressed Michelangelo that he called them the 'Gates of Paradise'. Made of sandstone and faced with marble incorporating many reused fragments of Roman buildings, the exterior features many sculptural groups and two massive porphyry columns.

The interior of the baptistry is clad in marble, while the inside of the dome which roofs the structure is inlaid with magnificent gold mosaics. The floor is covered in marble featuring a design based on the zodiac. Unusually, the baptistry also houses a number of tombs, including that of the antipope John XXIII which is considered a significant early-Renaissance sculptural work.

Giotto's campanile

The campanile, or bell tower, was designed by the celebrated painter Giotto di Bondone and it houses seven bells. Standing next to the cathedral, it is built from the same coloured marbles and so blends in well with its neighbour. The tower is square in plan with sides measuring 15 metres (47 feet) and it soars 87 metres (278 feet) high. Embraced by polygonal buttresses at its corners, it's divided into five separate levels – the upper three of which contain windows. Each of the three top levels is larger than the one below it in every dimension. These differences in size counter the effect of perspective so when viewed from below, the three top levels of the tower look equal in size. Although Giotto originally intended the campanile to be surmounted by a tall spire, after his death it was decided to build a large projecting terrace instead, which lends the tower a dramatic 'broken off' look.

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Jerusalem under siege

From Roman battles to WWI, this city has seen more than its fair share of conflict

In its long history, the city of Jerusalem has been besieged over 20 times. One of the oldest cities in the world, it has been the scene of Roman civil wars, holy crusades and even a world war.

The first siege of the Common Era was when the city was under Roman rule in 70 CE. Started by the Great Jewish Revolt in 66 CE, the Jews were incensed when a Roman official stole from the synagogue. Jews rose up against their oppressors' rule and established Jerusalem as the centre of rebellion. Subsequently, Emperor Vespasian ordered a force led by General Titus to retake the city. Battering rams, catapults and siege towers were used to destroy the walls and sacred relics from the city's temple were stolen. The Arch of Titus in Rome was built to commemorate the victory.

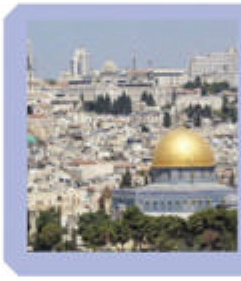
Perhaps the most famous of all Jerusalem's conflicts, though, were the Crusades. In the First Crusade of 1099, a Christian army with 12,000 infantry and 1,500 cavalry took the city. Siege towers and scaling ladders were used to overwhelm the defences of one of the best-defended metropolises of the age.

This victory led to a counterattack in 1187 from Saladin of the Ayyubid Dynasty. The city, still under Christian rule, was defended by Balian of Ibelin. At first, Saladin negotiated for a peaceful surrender but after it was rejected he began besieging Jerusalem.

He focused his attacks on the Tower of David and the Damascus Gate. The assault was repelled so the attention was turned to the Mount of Olives, which had no gate. This proved to be a tactical masterclass and, just as the Christian stronghold was about to fall, Balian offered a negotiated surrender to which Saladin eventually agreed. The later Third Crusade led by Richard the Lionheart and Philip II in 1189 aimed to reclaim the city, but ultimately failed.

The next major siege was centuries later in 1917 during World War I. A battle between the British and the Ottoman Empire, the city fell into Allied hands after several days of fighting. The city remained under British rule until 1948, when the Arab-Israeli War divided Jerusalem between Israel and Jordan, leading to decades of internal conflict. Today, it is the capital of two sovereign states: Israel and Palestine.

Why is Jerusalem so sought after?

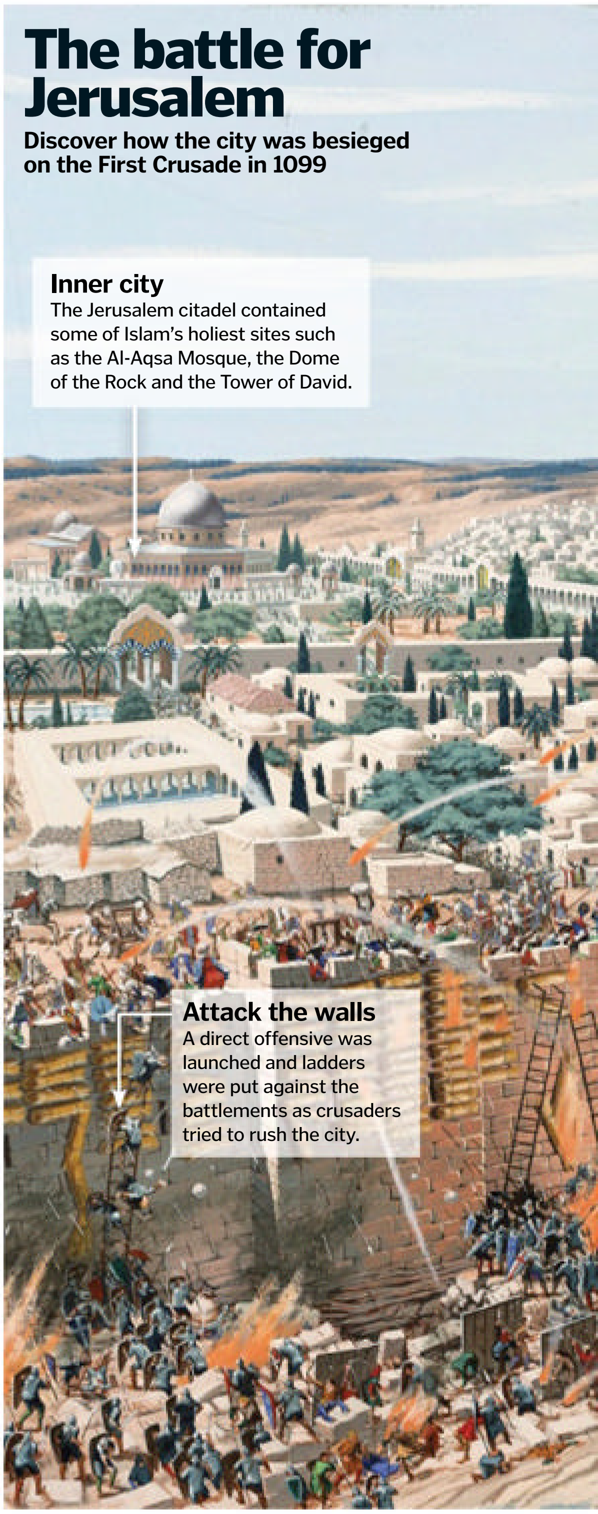


Jerusalem has been regarded as a city of religious significance for Jews, Christians and Muslims for over 2,000 years. For Crusaders, the city needed to be recaptured from Muslim rule, as it was essential to pilgrimages. In Judaism, Jerusalem is considered holy and is often known as Zion.

Jews believe the city was designed for them by God. For Islam, the city contains one of the holiest mosques after that in Mecca and is known as Al-Quds. Jerusalem was also geographically important for empires to get a foothold on the Middle East for military campaigns and trade.

The battle for Jerusalem

Discover how the city was besieged on the First Crusade in 1099



Inner city
The Jerusalem citadel contained some of Islam's holiest sites such as the Al-Aqsa Mosque, the Dome of the Rock and the Tower of David.

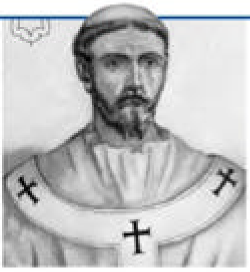
Attack the walls
A direct offensive was launched and ladders were put against the battlements as crusaders tried to rush the city.

Road to Jerusalem

Jerusalem was the main target for the First Crusade – here's how the conquest unfolded

Nov 1095

Christian armies from the West, encouraged by Pope Urban II, decide to recapture the Holy Land from the Muslims.

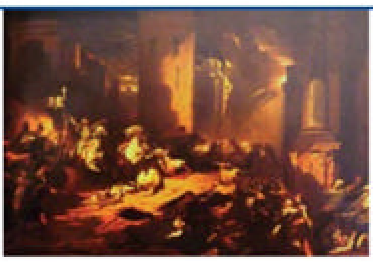


Dec 1096

Western forces arrive in the Byzantine capital of Constantinople to begin the war.

Jun 1097

The Anatolian city of Nicaea is captured, followed by an eight-month siege of Antioch (right).



5 TOP FACTS
FAMOUS SIEGES

Gibraltar

1 The Great Siege of Gibraltar was a French and Spanish attempt to take over the British stronghold. Lasting over three years, the British held out despite navy blockades.

The Alamo

2 Fought during the Texas War of Independence in 1836, the Alamo is renowned for the bravery of 200 Texans who held out over a 13-day siege against 6,000 Mexicans.

Candia

3 Lasting for two decades, the Siege of Candia is the longest in history. 60,000 Ottomans attacked the Venetian city in Crete in 1648 and it eventually succumbed in 1669.

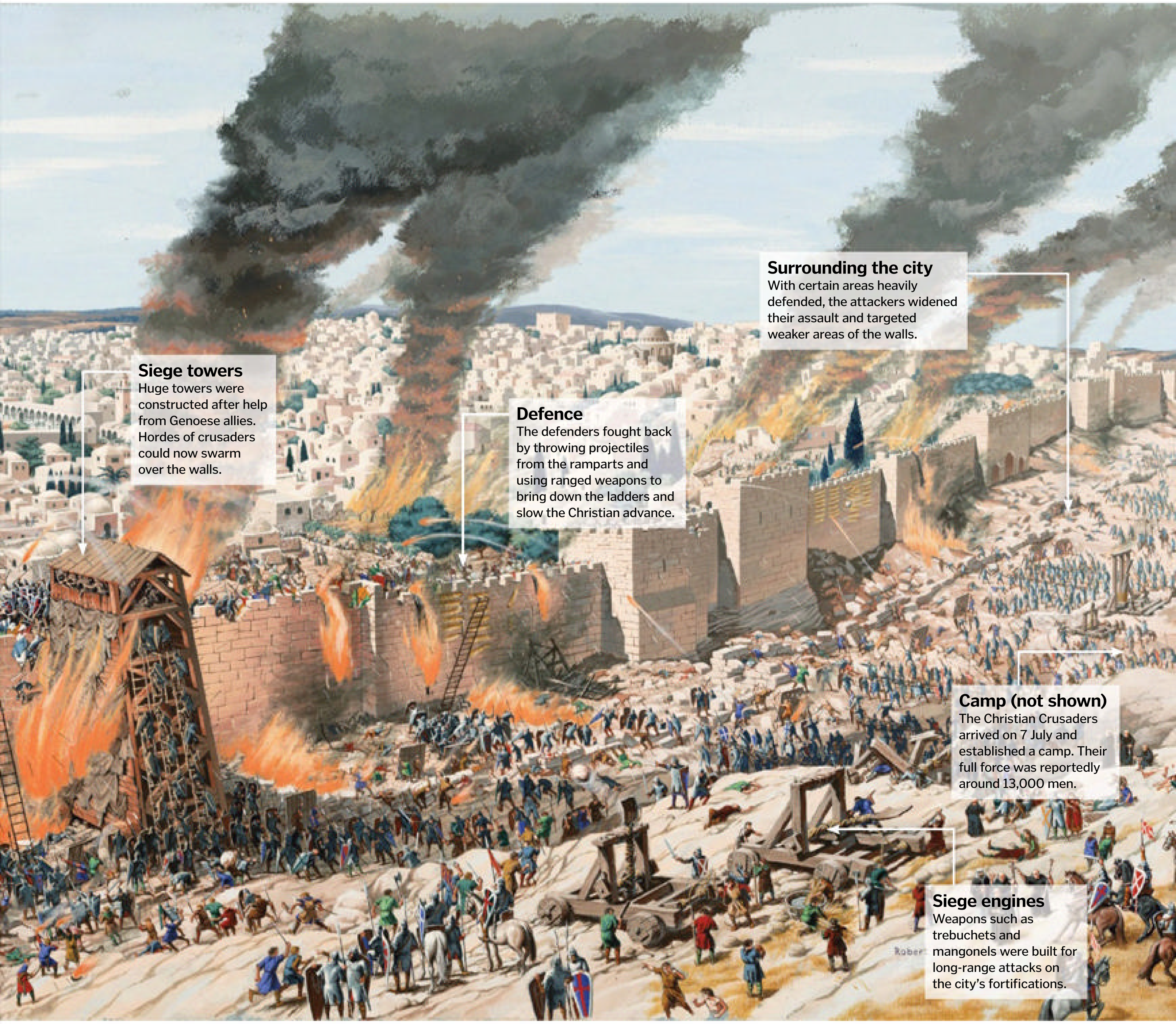
Constantinople

4 In 1453, just 10,000 men stood against 100,000 Ottomans. Cannons and warships led to not just the city's demise but also the fall of the Byzantine Empire.

Stalingrad

5 In 1942, Soviet city Stalingrad was surrounded by German forces. Fierce street-to-street fighting ensued, eventually resulting in a Russian victory and a turn of the tide in WWII.

DID YOU KNOW? *2005's Hollywood blockbuster film Kingdom Of Heaven is based on the 1187 Siege of Jerusalem*



Siege towers
Huge towers were constructed after help from Genoese allies. Hordes of crusaders could now swarm over the walls.

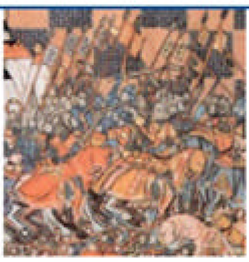
Defence
The defenders fought back by throwing projectiles from the ramparts and using ranged weapons to bring down the ladders and slow the Christian advance.

Surrounding the city
With certain areas heavily defended, the attackers widened their assault and targeted weaker areas of the walls.

Camp (not shown)
The Christian Crusaders arrived on 7 July and established a camp. Their full force was reportedly around 13,000 men.

Siege engines
Weapons such as trebuchets and mangonels were built for long-range attacks on the city's fortifications.

Jul 1097
The first big skirmish of the campaign at Dorylaeum results in heavy losses but a Christian win.



Dec 1097
The Muslims, led by Duqaq and Ridwan, strike back in two battles at Harenc but are repelled.

Jun 1098
The Battle of the Orontes sees a 75,000-strong Islamic army, low on morale, defeated by 15,000 Christians.

Jun 1099
The Siege of Jerusalem begins and the Crusaders are victorious by July (right).

Aug 1099
At the Battle of Ascalon, an Egyptian force of 50,000 is defeated by the Crusaders. With Jerusalem still under Christian control, the First Crusade ends.

© Getty; Thinkstock

Buckingham Palace uncovered

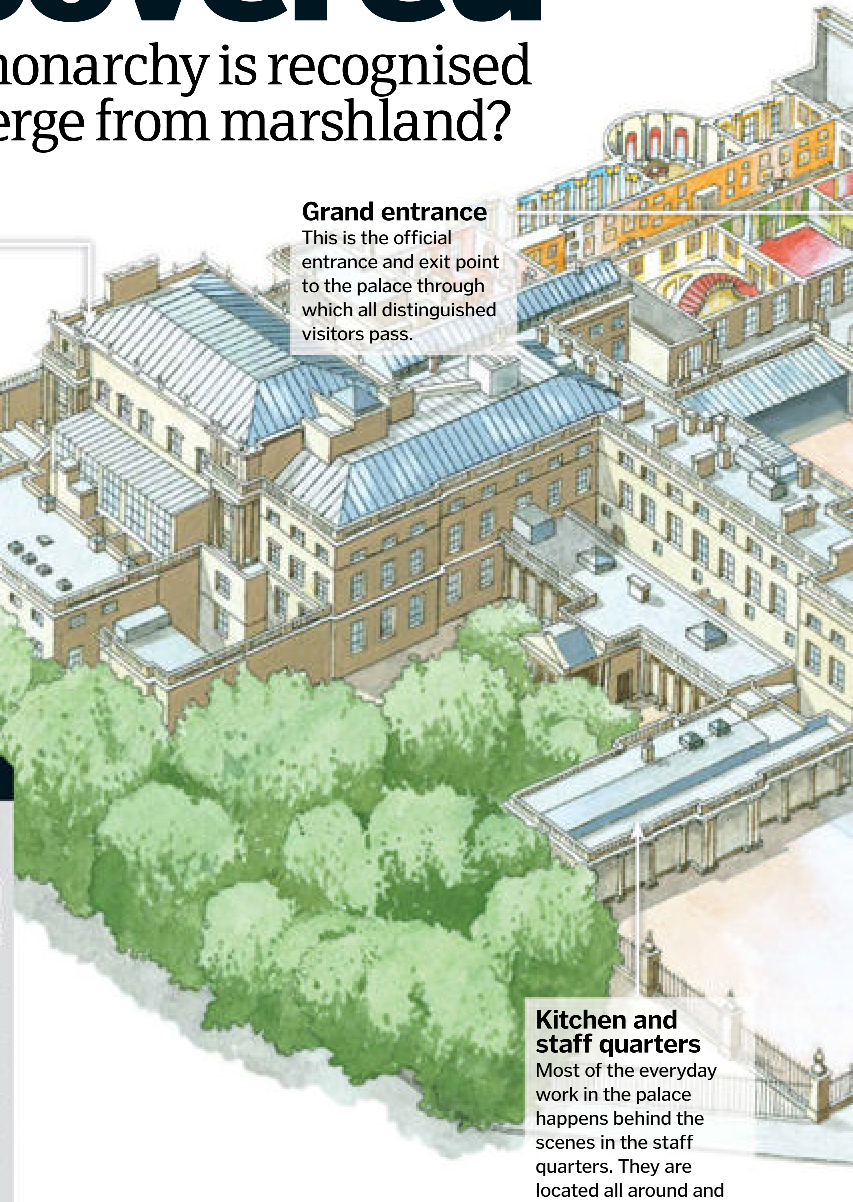
The London home of the British monarchy is recognised the world over, but how did it emerge from marshland?

Although one of London's most popular historic landmarks, Buckingham Palace as we know it today is less than 200 years old. Part of the medieval manor of Ebury, the land on which the palace stands, came into royal possession under Henry VIII.

Planted up as a mulberry garden by King James I (1603-1625) in an attempt to rear silkworms, the site of the future palace passed through various hands before Goring House, Arlington House and then Buckingham House were built on the same site in less than 150 years. Little is known about these houses, but they are thought to have stood where the south wing of the palace is located today.

In 1761 George III purchased Buckingham House for his wife, Queen Charlotte, as a quiet family home close to St James's Palace. A rather simple redbrick building, the king remodelled the house in 1762 and it was redesigned again on the accession of George IV in 1820. In 1826 the king decided to transform the old-fashioned house into a palace. The celebrated architect John Nash doubled the size of the building by adding a new suite of rooms in a French neoclassical style. The north and south wings of the old house were demolished and rebuilt on a larger scale, with a triumphal arch – the Marble Arch – as the courtyard's centrepiece.

With the accession of William IV, Nash was replaced by Edward Blore who finished work on the palace. The king, however, did not care for the building, failed to move in and even offered ▶



State ballroom
The largest room in the palace, the ballroom was added by Queen Victoria in 1854. It is 37m (121ft) long, 18m (59ft) wide and 13.5m (44ft) high.

Grand entrance
This is the official entrance and exit point to the palace through which all distinguished visitors pass.

Kitchen and staff quarters
Most of the everyday work in the palace happens behind the scenes in the staff quarters. They are located all around and even under the palace.

The statistics...

Buckingham Palace

Architects: John Nash, Sir Aston Webb, Edward Blore and others

Built: 1762-1914

Area: 77,000m² (830,000ft²)

Height: 24m (79ft)

Number of rooms: 775

Cost: Estimated at over £1bn ($1.7bn) today

The palace over time

Take a tour through Buckingham Palace's history and discover the key events that made it the landmark it is today

1536
Land sold
King Henry VIII takes the Manor of Ebury, which includes the land where the palace now sits, off Westminster Abbey and leases it to royal landlords.

1624
First house built
Sir William Blake builds the first house on the site. Bought by Lord Goring in 1633, the original structure is extended and becomes known as Goring House.

1674
Fire!
Purchased by Henry Bennet, First Earl of Arlington, Goring House burns down in 1674. Its replacement is called Arlington House.

5 TOP FACTS
ROYAL RESIDENTS

Queen Elizabeth II
1 The palace is the Queen's London home. Inhabiting her own quite modest private apartments, she is usually absent during August and September each year.

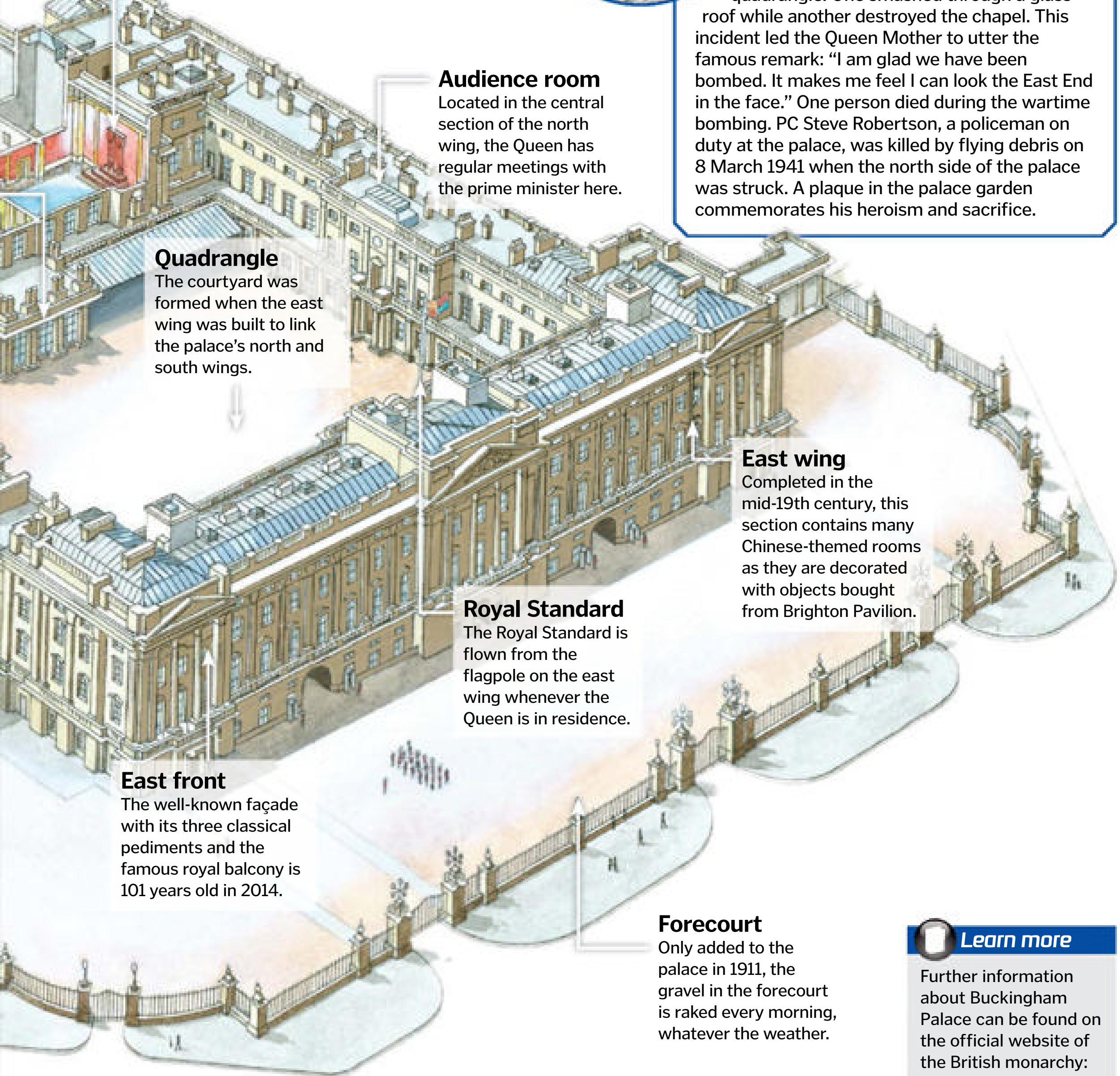
The corgis
2 The Queen has two corgis, Holly and Willow, and two 'dorgis' (corgi/dachshund crosses), Candy and Vulcan. The royal corgis travel with her throughout the year.

Queen Victoria
3 Britain's longest-reigning monarch, Victoria improved the palace by adding the east wing and state ballroom, but after Prince Albert's death in 1861, she rarely visited it.

Duke of Edinburgh
4 Since his marriage to Queen Elizabeth in November 1947, Prince Philip has lived alongside her at Buckingham Palace. He has his own private office and apartments.

King Edward VII
5 King Edward VII is the only monarch to date who was both born and died at Buckingham Palace. The king was born there in 1841 and passed away in 1910.

DID YOU KNOW? *There are over 350 working clocks and watches in Buckingham Palace, one of the world's largest collections*



Throne room
Used for royal receptions, this impressive room is most often seen as the backdrop to formal royal wedding photographs.

Audience room
Located in the central section of the north wing, the Queen has regular meetings with the prime minister here.

Quadrangle
The courtyard was formed when the east wing was built to link the palace's north and south wings.

East wing
Completed in the mid-19th century, this section contains many Chinese-themed rooms as they are decorated with objects bought from Brighton Pavilion.

Royal Standard
The Royal Standard is flown from the flagpole on the east wing whenever the Queen is in residence.

East front
The well-known façade with its three classical pediments and the famous royal balcony is 101 years old in 2014.

Forecourt
Only added to the palace in 1911, the gravel in the forecourt is raked every morning, whatever the weather.

Under fire

The palace suffered nine direct hits from bombs in WWII, but suffered little damage. However, on 13 September 1940, when King George VI and Queen Elizabeth the Queen Mother were in residence, bombs hit the palace quadrangle. One smashed through a glass roof while another destroyed the chapel. This incident led the Queen Mother to utter the famous remark: "I am glad we have been bombed. It makes me feel I can look the East End in the face." One person died during the wartime bombing. PC Steve Robertson, a policeman on duty at the palace, was killed by flying debris on 8 March 1941 when the north side of the palace was struck. A plaque in the palace garden commemorates his heroism and sacrifice.

5 other royal pads

1 Windsor Castle
The Queen's official residence and the largest occupied castle in the world. Inside the walls is St George's Chapel, home to the Knights of the Garter and the burial place of ten British monarchs.

2 Sandringham House
The private home of the sovereign since 1862. The royal family usually spend Christmas here and stay until February each year.

3 Palace of Holyroodhouse
The Queen's official residence in Scotland, founded as a monastery in 1128. Situated at the end of the Royal Mile in Edinburgh, the Queen is usually in residence for a week at the end of June each year.

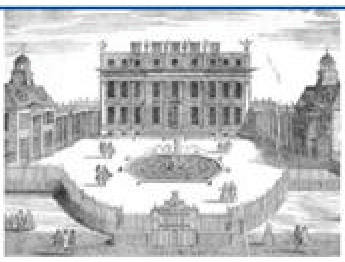
4 Clarence House
Built in the early-19th century. The Queen lived at Clarence House after her marriage to the Duke of Edinburgh in 1947. Today it's the official home of the Prince of Wales, the Duchess of Cornwall and Prince Harry.

5 Balmoral Castle
The Queen's private home in the Scottish Highlands, the Balmoral estate was bought and the present castle built by Queen Victoria and Prince Albert around 1850.

Learn more

Further information about Buckingham Palace can be found on the official website of the British monarchy: **bit.ly/1mLj944.**

1703
Buckingham House is built
The house forming the core of the present palace is made for the Duke of Buckingham by architect William Winde.



1761
Royal residence
George III buys Buckingham House for his wife, Queen Charlotte, as a family home close to St James's Palace.

1762
Extreme makeover
King George III employs Sir William Chambers to completely remodel the now old-fashioned house, at a cost of £73,000 – a huge sum in the 18th century.

it to Parliament as their new home after the Palace of Westminster (the Houses of Parliament) was destroyed by fire in 1834. But Queen Victoria decided to make Buckingham Palace her home and, after moving into the house in 1837, decided to have it enlarged as the palace had too few bedrooms for visitors and no nurseries. Blore designed a new east wing and had the Marble Arch moved to its present home at the north-east corner of Hyde Park. The east wing was constructed using French stone and was the last major addition to the palace.

This was not the end of construction work. In 1911, the present forecourt was formed with its impressive gates and railings, where the changing of the guard takes place today (see boxout). Just two years later the stone on the east wing's façade was discovered to have deteriorated so badly due to London's polluted atmosphere that it needed to be replaced. Sir Aston Webb produced a new design and, after a year of preparation, the new Portland stone façade was erected in just 13 weeks.

The palace's most impressive rooms are the state rooms, most of which are in the west wing. These consist of a sequence of theatrically magnificent interiors, designed to impress visitors and magnify the glory of the British monarchy. The state rooms are reached by ascending the grand staircase. The throne room, the blue drawing room and the white drawing room are the principal reception rooms, while the ballroom is frequently used for investitures. Electricity was first installed in the ballroom in 1883 and over the next four years it was extended throughout the palace. Today there are some 40,000 light bulbs in use and since 2005 traditional bulbs have been replaced with LED low-energy bulbs wherever possible.

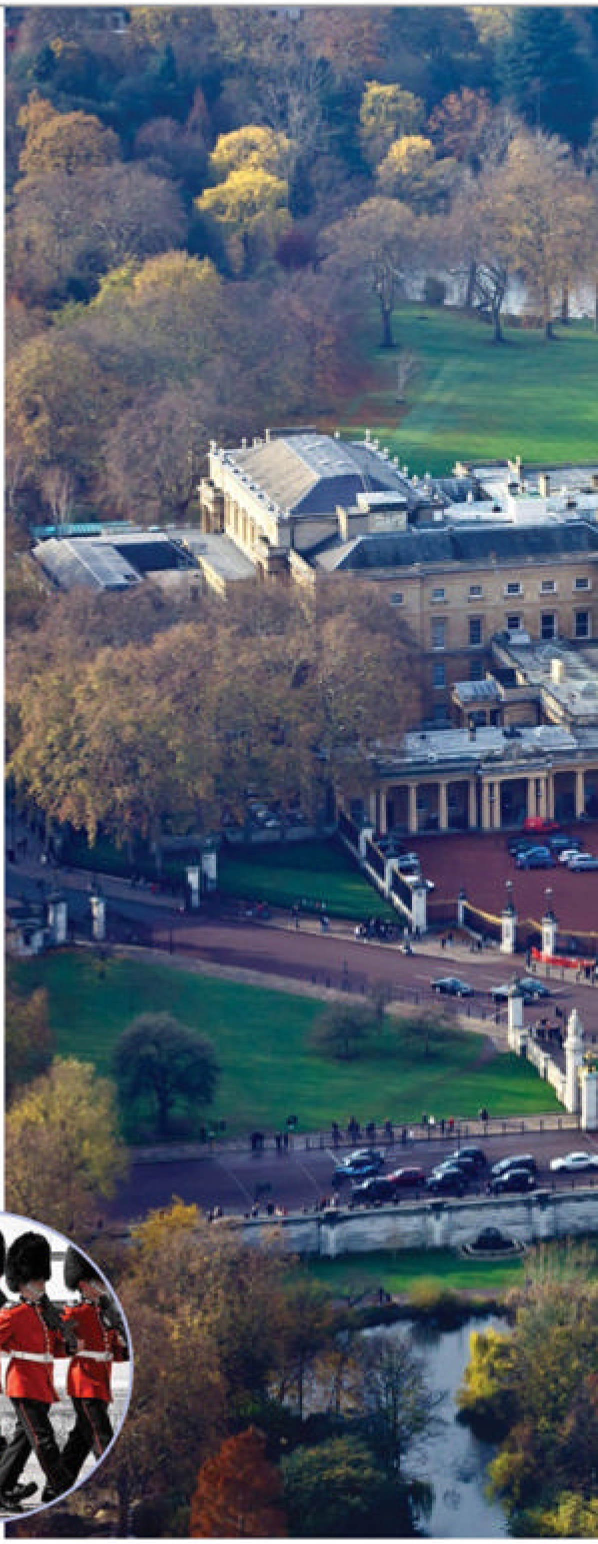
Of the palace's 775 rooms, there are 19 state rooms, 52 royal and guest bedrooms, 188 staff bedrooms, 92 offices and 78 bathrooms. There are some 1,514 doors and 760 windows in the palace; incidentally all the windows are cleaned every six weeks. Aside from the state, private and staff apartments, the palace has its own chapel, post office, swimming pool, staff cafeteria, doctor's surgery and even a cinema. However, despite rumours to the contrary, the palace does not have its own private Underground station!

The gardens are private and surrounded by high walls. They cover 16 hectares (40 acres) and include a lake, tennis court and helipad. Over 99 per cent of green waste produced in the gardens is recycled on site. They are thought to contain about 30 different species of bird and over 350 species of wild flowers. The setting for the annual royal Garden Parties introduced by Queen Victoria in 1868, the gardens have also hosted a charity tennis competition, pop and classical music concerts and a children's party.

Although Buckingham Palace claims to be the world's largest working palace, there are other bigger contenders such as the Apostolic Palace in the Vatican City, Rome, the Royal Palace of Madrid in Spain and the Istana Nurul Iman Palace – home to the sultans of Brunei – which stands on the northern coast of Borneo. Whether or not Buckingham Palace is the world's largest operational palace, it is nonetheless an instantly recognisable symbol of London, the royal family and Britain as a whole.

Changing of the guard in focus

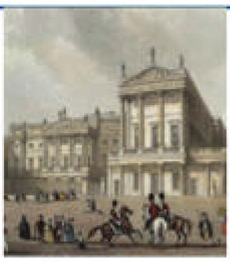
The changing of the guard, or guard mounting, is the process during which the new guard relieves the old guard. Dating back to the 17th century, the household troops stand sentry over the reigning sovereign and have been present at Buckingham Palace since 1837. Taking place at 11.30am each morning from May to July and on alternate days through the rest of the year, the ceremony is accompanied by a guards band, which plays a range of music, including themes from films, musicals and even pop songs. Over 2 million people watch the changing of the guard each year. The guard's uniform of black trousers, red jackets and tall bearskin hats has become synonymous with the British royal family and Buckingham Palace.



1826

House to palace

George IV transforms Buckingham House into a palace. The king employs John Nash and asks Parliament for £450,000 to cover the work.



1830

All change

George IV dies and William IV takes the throne. John Nash is dismissed for having spent nearly £500,000 on the palace and Edward Blore is appointed to finish the job.

1837

Queen Vic moves in

Queen Victoria is the first sovereign to take up residence in Buckingham Palace, in July. It is just three weeks after her accession to the throne.

1847

East wing completed

More space is needed in the palace so an east wing is added to Edward Blore's design. This wing holds the balcony where the royal family appear on special occasions.

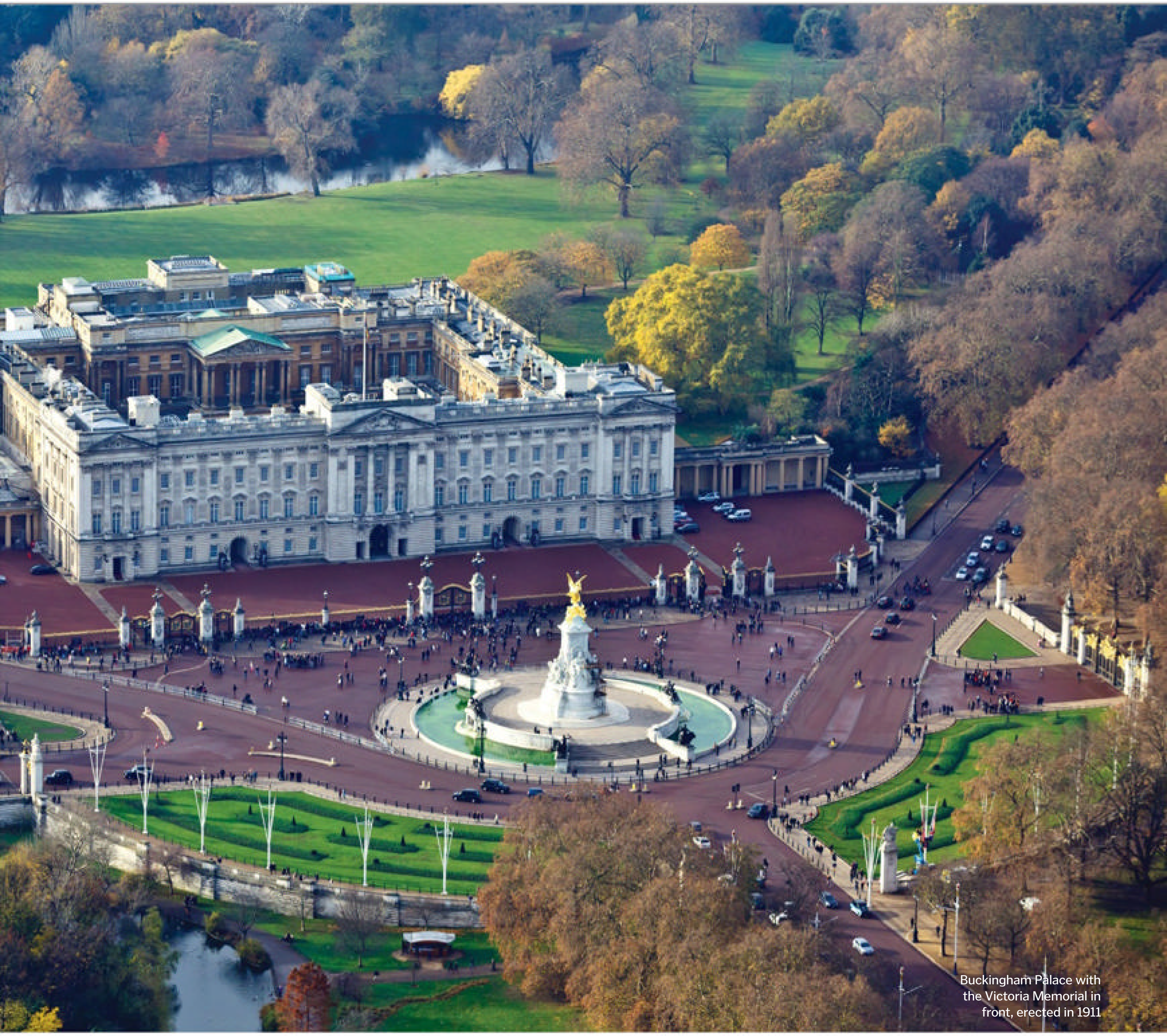
RECORD BREAKERS
FACE THE FACTS

201,948

PORTRAIT BY MOST ARTISTS

For three nights in April 2012, an image of the Queen was projected onto Buckingham Palace, made up of 201,948 self-portraits created by British children.

DID YOU KNOW? *Although Buckingham Palace is known the world over, it still has a unique postcode: SW1A 1AA*



Buckingham Palace with the Victoria Memorial in front, erected in 1911

1911

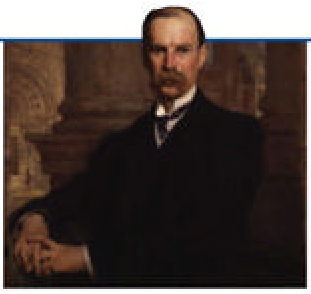
Changing of the Guard

As part of the Victoria Memorial scheme, the world-famous railings and forecourt in which the Changing of the Guard takes place are laid out in front of the palace.

1913

Face-lift

The soft French stone used on the east front is found to be crumbling, so Sir Aston Webb redesigns the façade and replaces the soft stone with hard Portland stone.



1945

Victory in Europe

On VE Day (8 May), the palace becomes the focus of celebrations, with the Royal Family appearing on the balcony to the cheers of the crowds on the Mall.

1993

Open house

Ever since the summer of 1993 the public have had access to Buckingham Palace's state rooms during August and September, when the Queen is not in residence.

© DK Images; Getty; Alamy

Massachusetts State House

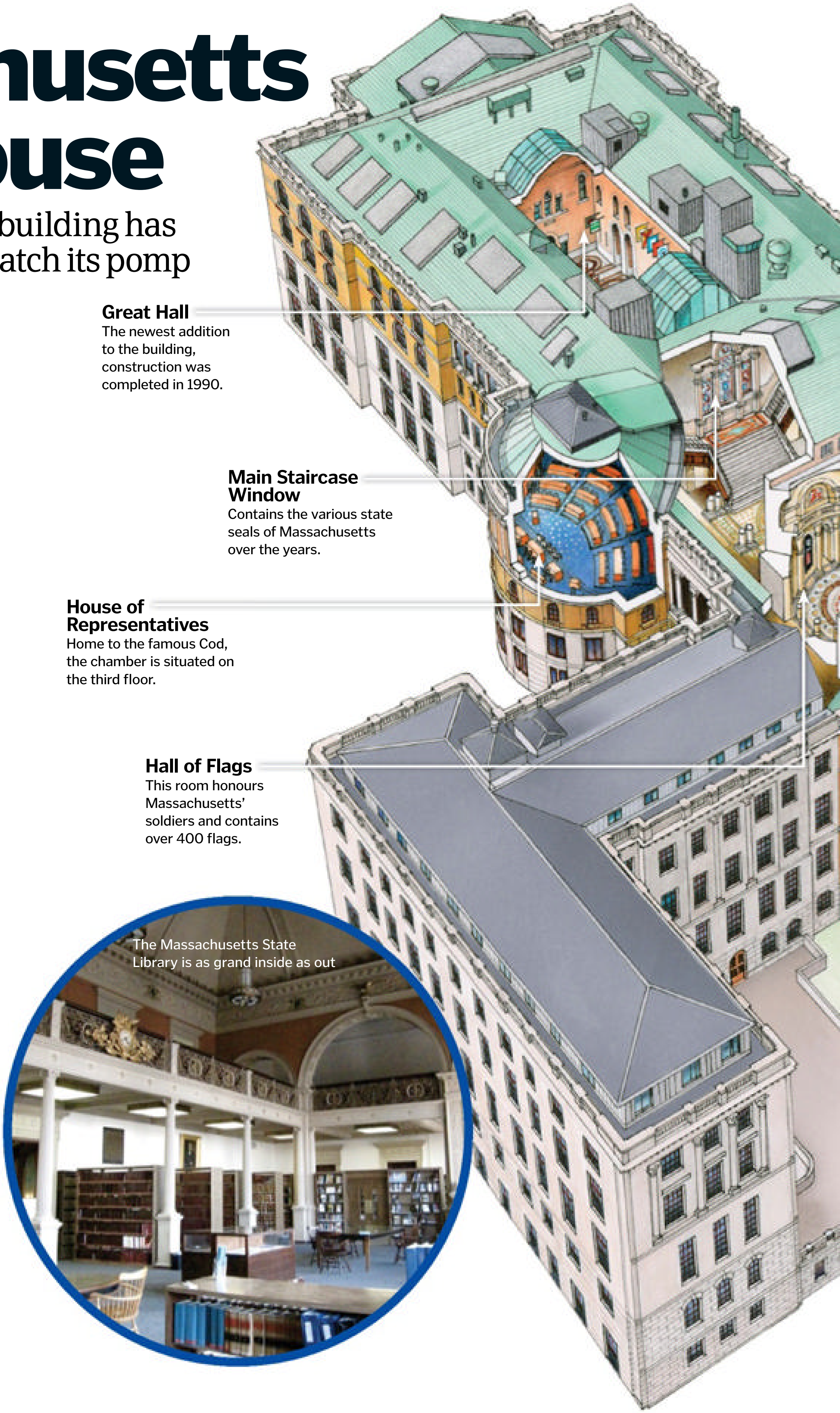
Why Boston's most iconic building has spades of symbolism to match its pomp

With the American Revolutionary War having ended in 1783, the still-young United States of America were striving to define their national identity. One of the ways in which the fledgling nation tried to achieve this was through the construction of grandiose and symbolic structures like Boston's capitol building, the Massachusetts State House.

The building was the brainchild of architect Charles Bulfinch, who took much of his inspiration from the two years he spent travelling around Europe. Construction commenced in 1795, with Patriots Samuel Adams and Paul Revere laying down its cornerstone in its location on top of Beacon Hill – a site once owned by John Hancock, the first elected governor of Massachusetts. Completed in 1798, it became an instant landmark, towering over the low-lying rest of the city and giving true credence to John Winthrop's epitaph of "a city on a hill."

The dome atop the State House is perhaps the section of its exterior that has changed the most over the years. Originally made of wood, it was overlaid with copper in the early-19th century before being covered in gold in 1874. During the Second World War it was painted dark for protection against the possibility of air raids during blackouts. The roof was finally re-gilded in 1997. On top of the dome itself is a wooden pine cone, symbolising the economic and cultural importance of the logging industry in the state's history.

Today, it still functions as the state's capitol building, hosting the Senate and House of Representatives' Chamber. Hanging up in the gallery in direct view of the Representatives is one of the most culturally significant sights in Boston: the Sacred Cod, which symbolises the importance of Boston's fishing industry to its prosperity. Combined with the numerous pieces of artwork and treasure in the building's confines, it's fair to say the building's history is extensive and far-reaching.



Great Hall
The newest addition to the building, construction was completed in 1990.

Main Staircase Window
Contains the various state seals of Massachusetts over the years.

House of Representatives
Home to the famous Cod, the chamber is situated on the third floor.

Hall of Flags
This room honours Massachusetts' soldiers and contains over 400 flags.

The Massachusetts State Library is as grand inside as out

5 TOP FACTS
BULFINCH DESIGNS

United States Capitol
1 Bulfinch oversaw construction of the Capitol Building between 1818 and 1826, having modified the original concept. He is responsible for the design of the dome in the centre.

University Hall
2 Having studied at Harvard, it's fitting that Bulfinch went on to design one of its most iconic buildings. It was built from 1813-1815 and is a US National Historic Landmark.

Maine State House
3 Based on his designs for the Massachusetts State, construction took place from 1829-32. It was later expanded on in 1911, with much of the old building being demolished.

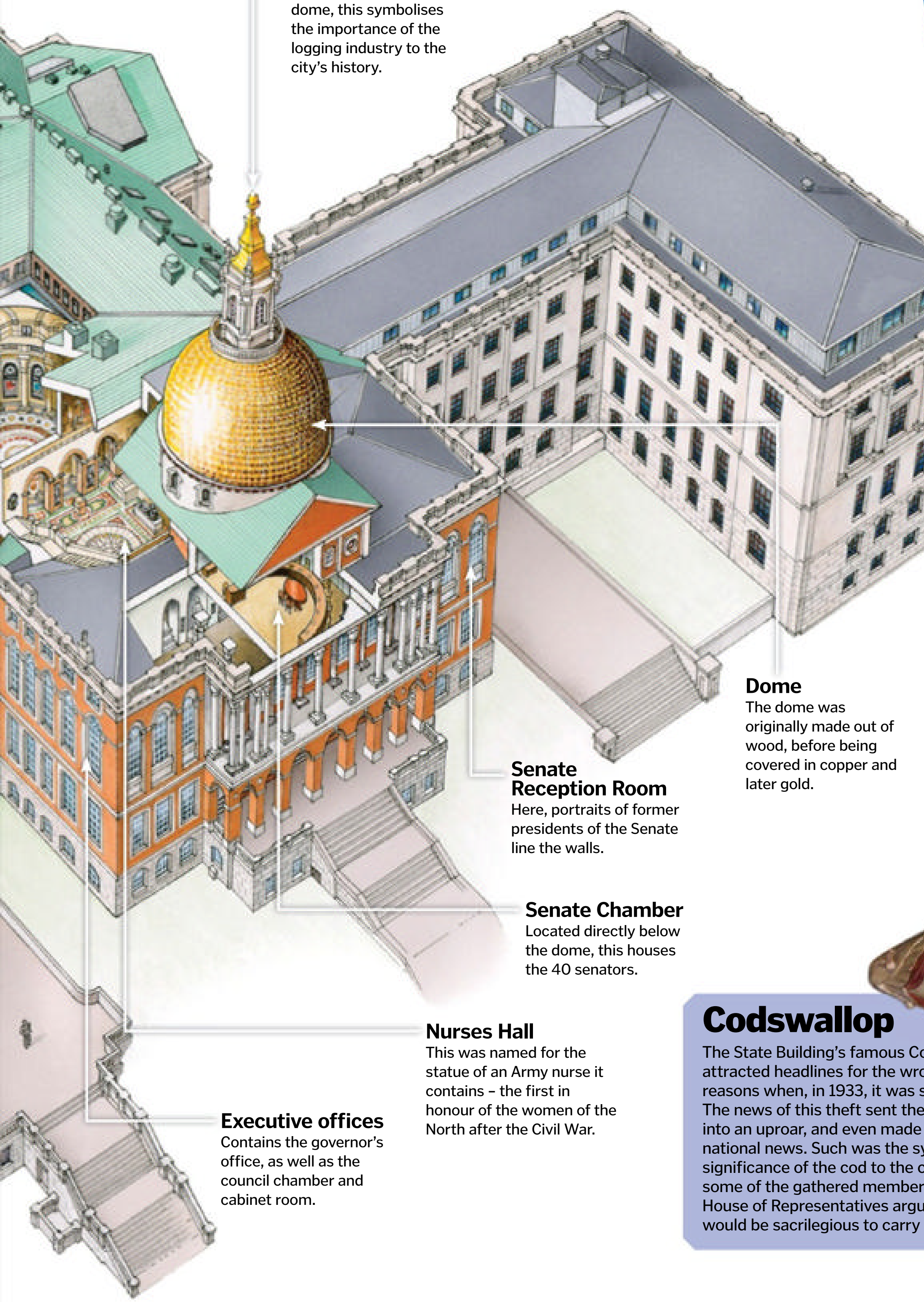
First Church of Christ Unitarian
4 Bulfinch's last project before working on the Capitol. Although smaller in scale, this is no less impressive than his previous work.

The Bulfinch Building
5 Part of the Massachusetts General Hospital, construction of the building to bear the architect's name took place from 1818-23, and is also a National Historic Landmark.

DID YOU KNOW? *The Massachusetts State House can be seen in numerous scenes in Martin Scorsese's 2006 film The Departed*

Inside the State House

Your guide to the most important features of the Massachusetts State House



Pine cone
Located on top of the dome, this symbolises the importance of the logging industry to the city's history.

Dome
The dome was originally made out of wood, before being covered in copper and later gold.

Senate Reception Room
Here, portraits of former presidents of the Senate line the walls.

Senate Chamber
Located directly below the dome, this houses the 40 senators.

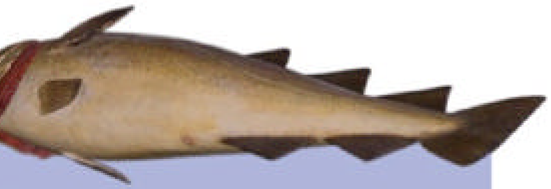
Nurses Hall
This was named for the statue of an Army nurse it contains – the first in honour of the women of the North after the Civil War.

Executive offices
Contains the governor's office, as well as the council chamber and cabinet room.

Inspirations for the State House's design

During his travels, Bulfinch drew on inspiration from a number of styles, which coalesced to form a building with a style of its own. One of the styles that can be most clearly observed in the building's design is Palladian in nature, drawing on the design themes present in the work of Italian architect Andrea Palladio (1508-80), notably the kind of symbolism seen in classical Greek architecture. A famous example of this can be seen in Somerset House, London (above), with the central part of the State House bearing the most obvious parallels with Palladian architecture.

In addition, Bulfinch's work evoked the neoclassical styles embodied by the likes of Scottish architect Robert Adam (1728-92), although in a move that evoked themes closer to home, wood was used for the columns in the colonnade, as well as for parts of the stairs and decorative bands on the columns.



Codswallop

The State Building's famous Cod attracted headlines for the wrong reasons when, in 1933, it was stolen. The news of this theft sent the city into an uproar, and even made national news. Such was the symbolic significance of the cod to the city that some of the gathered members of the House of Representatives argued it would be sacrilegious to carry on as normal without the famous fish looking over them.

The cod was eventually recovered (with only minor damage) by Harvard Yard police chief Charles Apted, with the cod-napping being blamed on the staff of *The Lampoon*, Harvard University's comedy magazine, although none if its members were ever charged.

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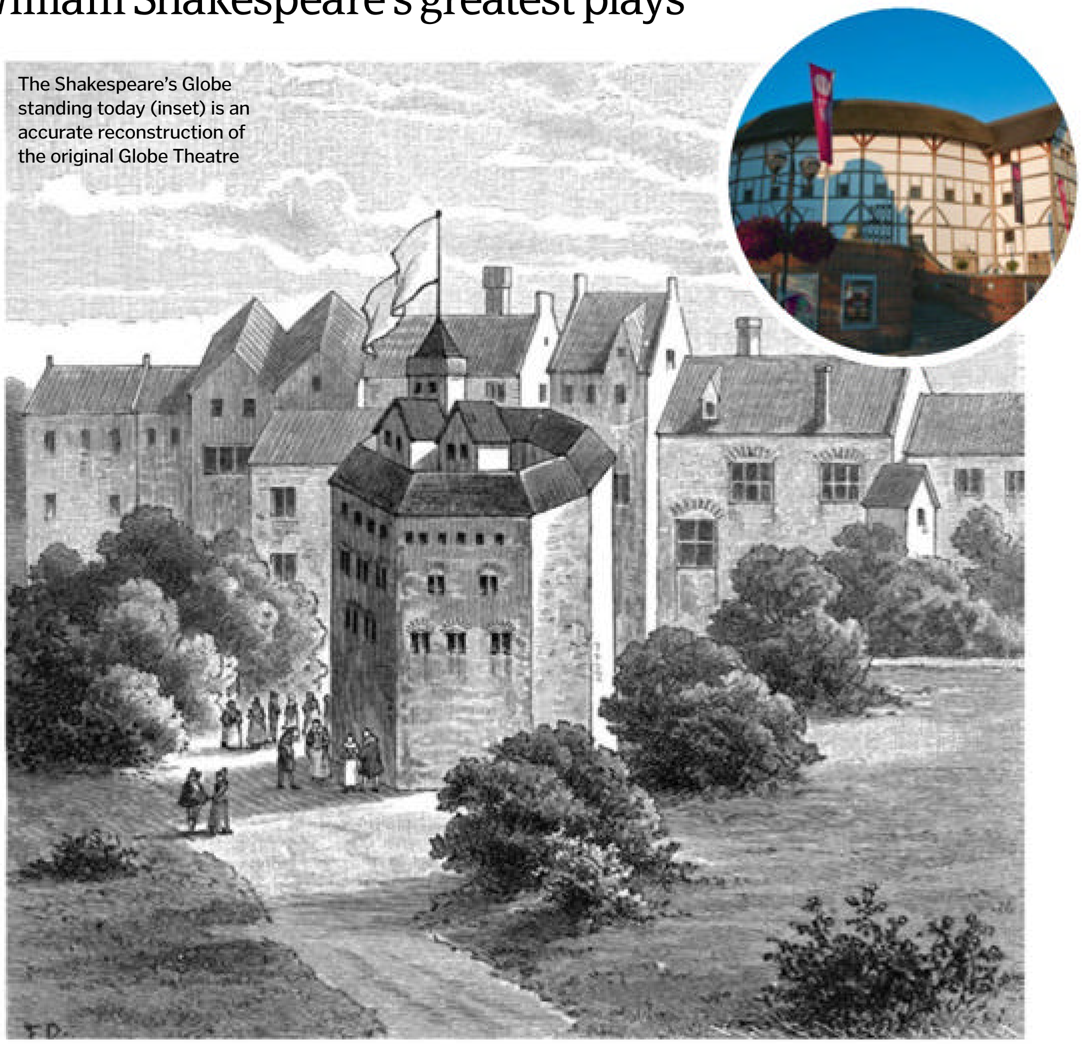
The Globe Theatre's story

The most famous and historic theatre in Britain – if not the world – the Globe was the original home to William Shakespeare's greatest plays

The Globe Theatre was an Elizabethan-era playhouse part-owned by the great playwright William Shakespeare. Built from the remains of an existing theatre in Shoreditch, London, made by English actor and theatre owner Richard Burbage and his brother Cuthbert, the Globe was constructed over just a few months in 1599. The playhouse became the home of the Lord Chamberlain's Men, a troupe of which Shakespeare and the Burbages were members. The group went on to perform many of the Bard's most famous plays there. Reportedly, the first performance was *Julius Caesar*, with subsequent plays such as *Richard II, Romeo And Juliet* and *A Winter's Tale* also shown there.

The Globe proved a great success, with its 3,000 capacity frequently tested to the limit, both in the cheap standing-only pit area as well as in the more prestigious tiered seating located around the inner walls. Unfortunately, however, on 29 June 1613 during a performance of *Henry VIII*, a theatrical cannon misfired and ignited the wooden beam and thatch roof, leading to the entire building burning down. Luckily, the success of the Globe's owners and its performances resulted in the theatre being rebuilt again in 1614, with the new playhouse continuing to host many acting troupes well after Shakespeare's death in 1616. In fact, it was not until 1642 that the theatre was closed down – a casualty of the English Civil War.


The Shakespeare's Globe standing today (inset) is an accurate reconstruction of the original Globe Theatre

The Globe over time

Check out some of the main events in the theatre's history now

1599: Grand opening

The Globe Theatre is opened on Bankside, London.

1601: *Richard II* runs

Shakespeare's acting troupe, the Lord Chamberlain's Men, are commissioned to stage *Richard II*.

1608: Blackfriars bought

The Globe's co-owner, Richard Burbage, acquires the lease for the Blackfriars Theatre, which is then used for winter performances.

1614: Globe rebuilt

Following a disastrous fire that burned down the Globe, it is rebuilt a year later on the original foundations.

1997: Resurrection

An accurate reconstruction of the Globe is built near to the site of the original building. It stages Shakespeare's works and is a popular tourist attraction to this day.

1644: Globe destroyed

The theatre is razed to the ground again – this time by order of the Puritans. Landowner Sir Matthew Brend builds tenement houses on the site in its place.

1642: Plays suppressed

In the English Civil War, Parliament issues an ordinance that forbids all stage plays. The Globe is shut down.

1616: Mortal coil

William Shakespeare dies aged 52 in Stratford-upon-Avon, where he is buried in the Holy Trinity Church.

A modern-day Globe

Theatre fans today can visit the modern reconstruction of the Globe. It was nevertheless made to be historically accurate, consulting the plans, construction methods and materials of the 1599 original, albeit with modern safety standards in mind. Shakespeare's Globe is built from 100 per cent English oak, with components linked with mortise and tenon joints – both features shared by the original – and also has the only thatched roof permitted in all London since the Great Fire of 1666. The attention to historical detail even extends to the pit area, which remains standing only, albeit with a concrete surface rather than the earthen/straw mix of the 16th/17th century. A second Shakespearean play venue, the Blackfriars Theatre, has been reconstructed and opened as the Sam Wanamaker Playhouse in January 2014.

5 TOP FACTS
GLOBE TRIVIA

Motto
1 The Globe's motto was 'Totus mundus agit histrionem', derived from Roman courtier Petronius' statement that 'all the world plays the actor' – hence its name, the Globe.

Shareholders
2 The Globe was owned by actors who were also shareholders in the Lord Chamberlain's Men. Shakespeare owned a single share, equal to 12.5 per cent.

Breeches on fire!
3 According to reports of the Globe fire in 1613, no one was seriously injured, the only incident involving a man's breeches being set alight and then put out with ale.

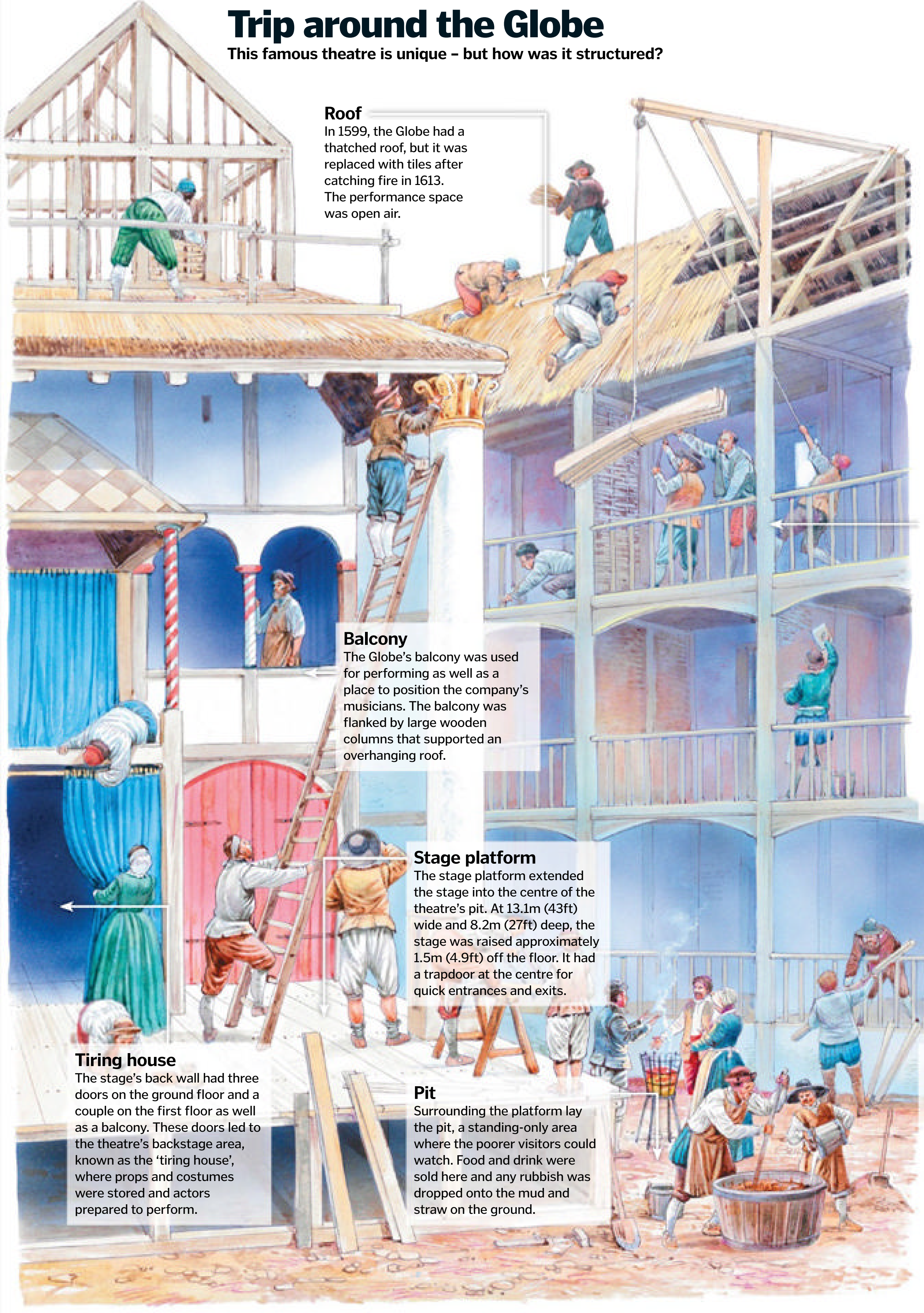
Puritan shutdown
4 Like all other theatres at the time, the Globe was closed down by Puritans in 1642 before being torn down two years later to make way for cheap residential housing.

Car park
5 Today, while an incredibly accurate reconstruction of the Globe exists – named Shakespeare's Globe – the remains of the original are located under a car park.

DID YOU KNOW? The modern reconstruction of the Globe is located 230m (750ft) from the original site

Trip around the Globe

This famous theatre is unique – but how was it structured?



Roof
In 1599, the Globe had a thatched roof, but it was replaced with tiles after catching fire in 1613. The performance space was open air.

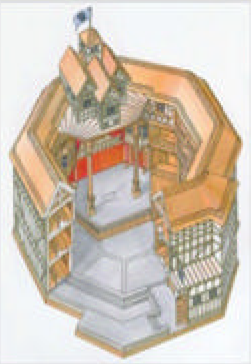
Balcony
The Globe's balcony was used for performing as well as a place to position the company's musicians. The balcony was flanked by large wooden columns that supported an overhanging roof.

Stage platform
The stage platform extended the stage into the centre of the theatre's pit. At 13.1m (43ft) wide and 8.2m (27ft) deep, the stage was raised approximately 1.5m (4.9ft) off the floor. It had a trapdoor at the centre for quick entrances and exits.

Tiring house
The stage's back wall had three doors on the ground floor and a couple on the first floor as well as a balcony. These doors led to the theatre's backstage area, known as the 'tiring house', where props and costumes were stored and actors prepared to perform.

Pit
Surrounding the platform lay the pit, a standing-only area where the poorer visitors could watch. Food and drink were sold here and any rubbish was dropped onto the mud and straw on the ground.

The statistics…



Globe Theatre

Opened: 1599
Capacity: 3,000
Stage width: 13.1m (43ft)
Stage depth: 8.2m (27ft)
Theatre diameter: 30m (100ft)
Closed: 1642

Storeys
The Globe had a three-storey seating arrangement used by the middle and upper classes. Basically the higher the seat, the more expensive it was.

Foundations
Despite appearing circular in design, with a diameter of just over 30m (98ft), the Globe's foundations were actually a 20-sided polygon (icosagon). At the centre of the theatre lay the rectangular stage platform.

Entrance (not shown)
There was one main entrance to the theatre, which was directly opposite the stage and led into the pit. Two sets of stairs near the entrance led into the upper seating tiers.

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Inside a Japanese castle

We find out how Himeji Castle – a 17th-century fortification – has stood firm despite several centuries of conflict and natural disasters

Built on a hill 45 metres (150 feet) above sea level in southern-central Japan, Himeji Castle has survived innumerable feudal battles, sieges, earthquakes and even a WWII bombing. While today it's famed as Japan's largest castle, construction of the original site began in 1333 with the building of a small fort. The fort wasn't turned into a castle stronghold until nearly 250 years later, towards the end of the civil war era. The addition of three moats and dozens of extra buildings – including three large towers and a huge, six-storey main keep, or tenshu – saw the striking white complex become one of the greatest Japanese castles ever built.

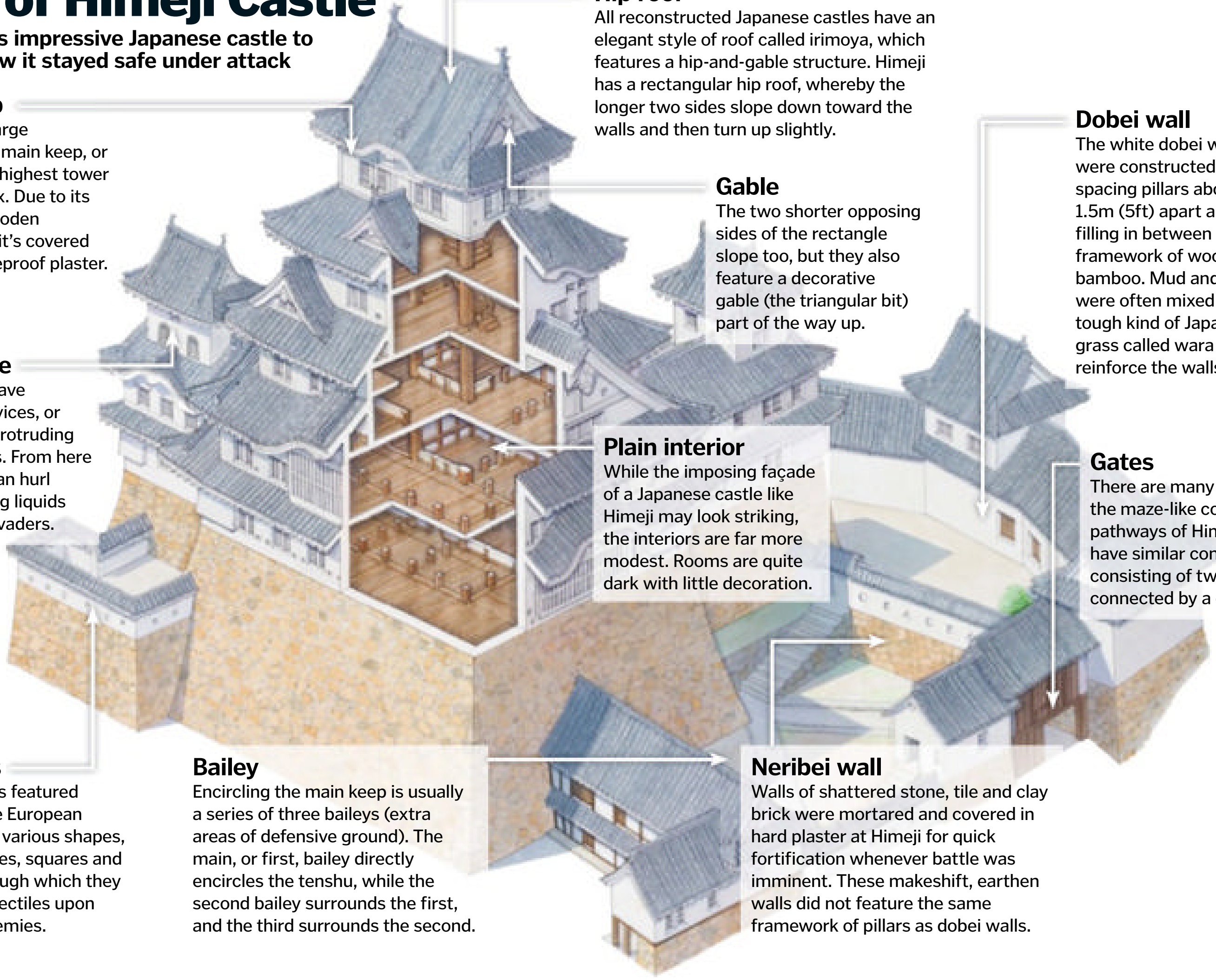
As is typical of traditional Japanese architecture, Himeji Castle is an elevated wooden structure featuring ornate tiling and embellishment. As well as gates, walls and other protective fixtures, Himeji and many other castles were equipped with a number of defensive devices to stall advancing foes.

Before they could even think about breaching the defences, the enemy would first have to navigate a frustrating maze of steep, snaking paths laid out around the castle walls. The physically demanding paths that seemed to lead directly to the main keep – but which often led instead to a dead-end – would disorientate and tire invaders. And even if they made it beyond the perimeter, the home team would then deploy an ingenious bevy of traps designed to outwit and injure the incoming aggressors, including conduits down which they would pour boiling oil or water.

Japan's best-preserved 17th-century castle, Himeji became a UNESCO World Heritage Site in 1993, which is quite remarkable considering what the region has endured, from earthquakes to attacks by US B-29 bombers. Of course, since the demolishment of the original 1333 fort, the castle has been rebuilt and remodelled by various rulers and architects, but what's interesting is that neither nature nor conflict has ever managed to get the better of Himeji.

Tour of Himeji Castle

Explore this impressive Japanese castle to find out how it stayed safe under attack



Main keep
Located in a large courtyard the main keep, or tenshu, is the highest tower in the complex. Due to its vulnerable wooden construction, it's covered with thick, fireproof plaster.

Hip roof
All reconstructed Japanese castles have an elegant style of roof called irimoya, which features a hip-and-gable structure. Himeji has a rectangular hip roof, whereby the longer two sides slope down toward the walls and then turn up slightly.

Gable
The two shorter opposing sides of the rectangle slope too, but they also feature a decorative gable (the triangular bit) part of the way up.

Dobei wall
The white dobei walls were constructed by spacing pillars about 1.5m (5ft) apart and filling in between with a framework of wood and bamboo. Mud and clay were often mixed with a tough kind of Japanese grass called wara to reinforce the walls.

Rock chute
Many keeps have ishi-otoshi devices, or rock chutes, protruding from the walls. From here the defence can hurl rocks or boiling liquids like oil onto invaders.

Plain interior
While the imposing façade of a Japanese castle like Himeji may look striking, the interiors are far more modest. Rooms are quite dark with little decoration.

Gates
There are many gates among the maze-like courtyards and pathways of Himeji, but all have similar construction, consisting of two columns connected by a crossbeam.

Loopholes
Japan's castles featured loopholes (like European arrow slits) of various shapes, including circles, squares and triangles, through which they could fire projectiles upon advancing enemies.

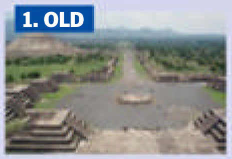
Bailey
Encircling the main keep is usually a series of three baileys (extra areas of defensive ground). The main, or first, bailey directly encircles the tenshu, while the second bailey surrounds the first, and the third surrounds the second.

Neribei wall
Walls of shattered stone, tile and clay brick were mortared and covered in hard plaster at Himeji for quick fortification whenever battle was imminent. These makeshift, earthen walls did not feature the same framework of pillars as dobei walls.

© Thinkstock

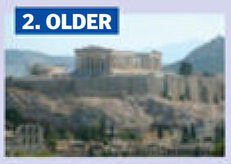
HEAD 2 HEAD
ANCIENT RELIGIOUS SITES

1. OLD



Teotihuacán
Built around 110 BCE to 250 CE in central Mexico, this city contains the Pyramid of the Sun, which is the third-largest pyramid in the world.

2. OLDER



The Acropolis
Constructed circa 500 BCE, the Acropolis in Greece's capital, Athens, includes several temples – the most famous of which is the Parthenon.

3. OLDEST

Stonehenge
Believed to have been built circa 2500 BCE, this enigmatic religious monument consisting of rings of standing stones is found in Wiltshire, UK.

DID YOU KNOW? *In 1974 a statue in the pagoda was found to contain what's believed to be one of Buddha's original teeth!*

The Fogong Temple Pagoda

The oldest wooden pagoda in China today is an architectural marvel by anyone's standards

The pagoda, traditionally a tiered tower built of stone, brick or wood, originated in historic eastern Asia. Usually associated with Buddhism and used for the storing of relics and sacred writings, the pagoda's architectural form has since been adopted by other religions and modified for secular use throughout the world.

The Sakyamuni Pagoda of Fogong Temple forms the central element in a complex of buildings erected by the Chinese Emperor Daozong in 1056. Said to have been built on the site of his family home, the emperor was a devout Buddhist and demonstrated this through the erection of this remarkable wooden, nine-storey structure. Covered with a profusion of carved and painted decoration, the pagoda is supported by 24 exterior and eight interior pillars, and roofed with highly ornate and glazed ceramic tiles.

The pagoda has needed occasional minor repairs over its lifetime and, despite surviving numerous natural disasters, the only serious threat it has faced came during the Second Sino-Japanese War (1937-1945) when Japanese soldiers raked the structure with small-arms fire. Today, the Fogong Temple Pagoda is a popular tourist attraction rather than a religious site, but its cultural significance is recognised in both China and beyond.

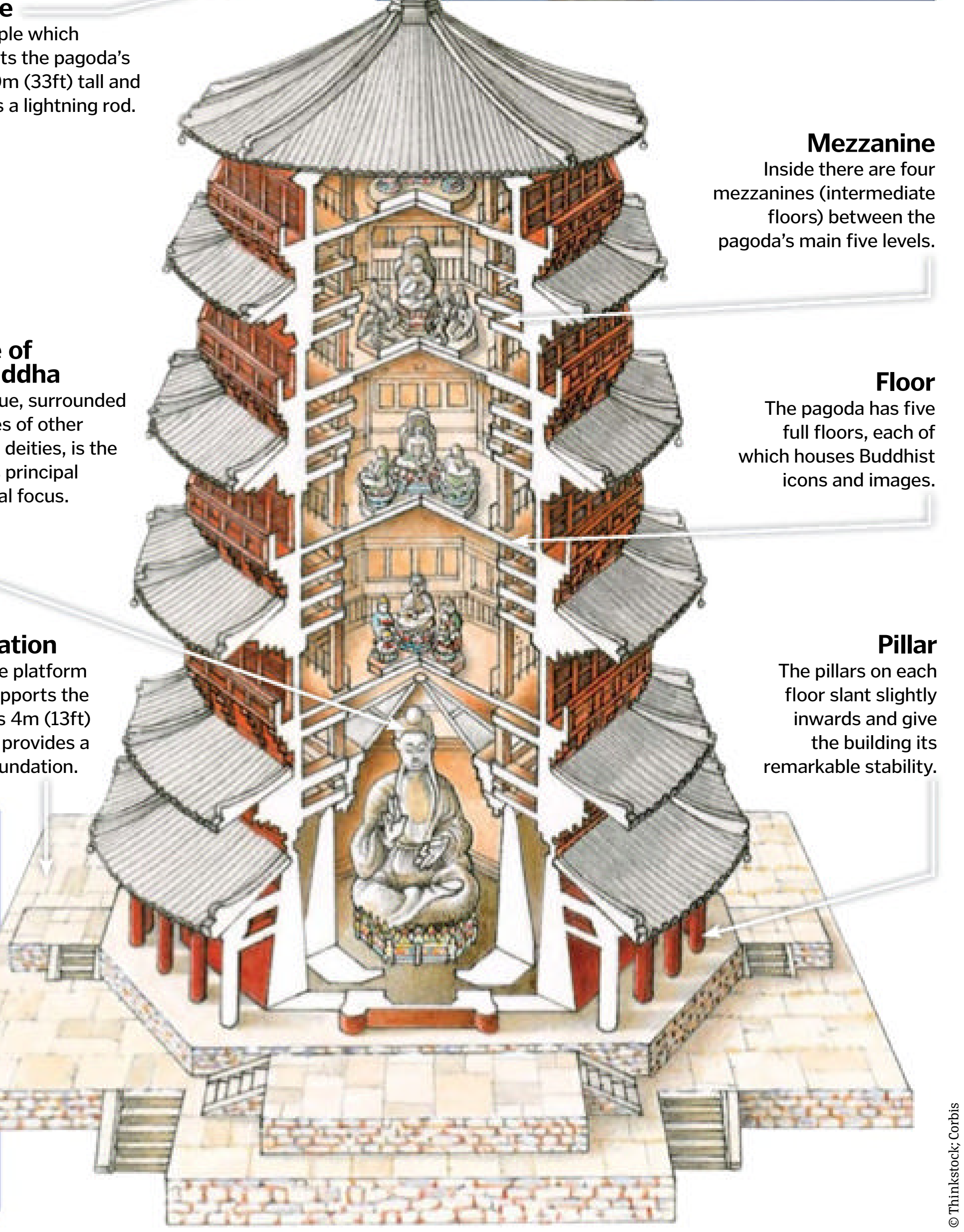
Built to last

During the first 50 years of its existence, the Fogong Pagoda survived seven earthquakes. The reason for the building's resilience is both its design and building material. The key to its wooden construction is found in its slanting pillars, which act as both external and internal buttresses, and the 54 kinds of bracket arms used to create it. These interlocking sets of brackets, called 'dougong' in Chinese (literally 'cap and block'), provide increased support for the weight of the horizontal beams that span the pagoda's pillars by transferring the weight over a larger area.

In this way a building consisting of many storeys may be constructed. Most importantly the use of multiple bracket arms allows structures to be elastic, which is how the Sakyamuni Pagoda has repeatedly withstood earthquakes that have flattened many of its neighbours.

Anatomy of a pagoda

Examine the Sakyamuni Pagoda of Fogong Temple from top to bottom



Steeple
The steeple which surmounts the pagoda's roof is 10m (33ft) tall and serves as a lightning rod.

Statue of the Buddha
This statue, surrounded by images of other Buddhist deities, is the pagoda's principal devotional focus.

Foundation
The stone platform which supports the pagoda is 4m (13ft) high and provides a stable foundation.

Mezzanine
Inside there are four mezzanines (intermediate floors) between the pagoda's main five levels.

Floor
The pagoda has five full floors, each of which houses Buddhist icons and images.

Pillar
The pillars on each floor slant slightly inwards and give the building its remarkable stability.

Fogong Temple
China

China is hoping for the Sakyamuni Pagoda to be included on the UNESCO list of cultural relics and is currently on a tentative list

© Thinkstock; Corbis

Brooklyn Bridge

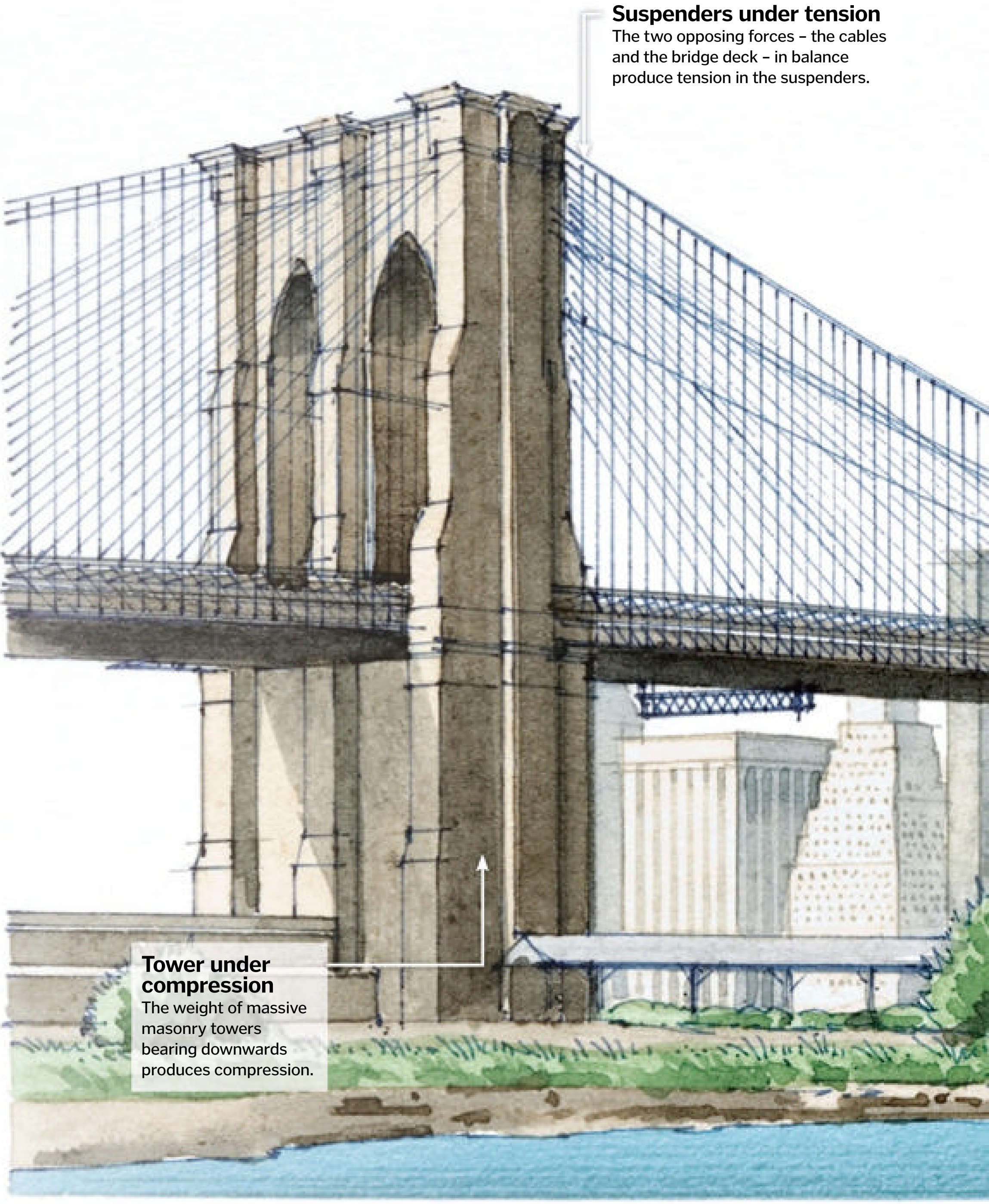
One of New York's most recognisable landmarks, the Brooklyn Bridge was the first-ever steel-wire suspension bridge

Built between 1870 and 1883, the Brooklyn Bridge links Brooklyn and Manhattan by spanning the East River in New York City. Designed by a German immigrant, John Augustus Roebling, it was his son, Washington Roebling, and daughter-in-law, Emily, who actually oversaw most of the construction after John's unexpected death just months before building commenced.

The bridge consists of two main elements. Firstly, there are the two anchorages that are positioned either side of the river and between them are two towers (also known as piers) which stand some 84 metres (277 feet) high. Consisting of limestone, granite and cement, the towers – designed in a neo-Gothic architectural style – stand on concrete foundations that run 13.4 metres (44 feet) and 23.8 metres (78 feet) deep on the Brooklyn and Manhattan sides, respectively.

Secondly, the bridge itself is constructed from iron and steel-wire cables, with a layer of tarmac on the main deck. At 26 metres (85 feet) wide and 1,825 metres (5,989 feet) long, the Brooklyn Bridge was the longest suspension bridge in the world when first built and held the record for over 20 years. Roebling's design includes many redundancies, such as a diagonal stay system between cables and stiffening trusses, which make the bridge very safe; indeed, even if one of the main support systems were to fail altogether the bridge would sag, rather than completely collapse.

More unusually, the bridge also has its own nuclear fall-out shelter built into one anchorage. Having fallen out of use and been forgotten, the shelter was rediscovered in 2006, along with provisions from the Cold War era. Designated a National Historic Landmark in 1964, since the Eighties the bridge has been floodlit at night to highlight its distinct architectural features. Initially intended to carry motor vehicles, trains, street cars, bicycles and pedestrians, since the Fifties, the bridge has only taken cars, cyclists and foot traffic. Over 120,000 vehicles, 4,000 pedestrians and 3,100 cyclists cross it every day.



Suspenders under tension
The two opposing forces – the cables and the bridge deck – in balance produce tension in the suspenders.

Tower under compression
The weight of massive masonry towers bearing downwards produces compression.

RECORD BREAKERS
SUPER SPAN

1,991m

LONGEST SUSPENSION BRIDGE

When completed in 1883, the Brooklyn Bridge was a record holder, but today it has been superseded by the Akashi Kaikyo Bridge in Japan, with a main span of 1,991 metres (6,532 feet).

DID YOU KNOW? *In 1884, showman PT Barnum paraded 21 elephants over the Brooklyn Bridge, proving its stability*

The origins of suspension bridges

In a suspension bridge the deck – the load-bearing portion – is hung below suspension cables on vertical suspenders which bear the weight. Although bridges of this design first seem to have been invented in 15th-century Tibet, it was really the 19th century which saw their application on a massive scale.

The materials used in the construction of the Brooklyn Bridge were sourced in the US. The granite blocks were quarried in Maine and delivered to New York by boat. The wire rope and steel cable were produced in local factories, while the pigment used in the red paint with which the bridge was originally covered came from the mines at Rawlins, Wyoming.

The design and construction techniques employed in the Brooklyn Bridge have changed little in their essentials over the last century or so. Although at least 81 suspension bridges today are longer than the Brooklyn Bridge, they are all fundamentally the same – except that now the materials tend to be drawn from all over the globe rather than sourced locally.

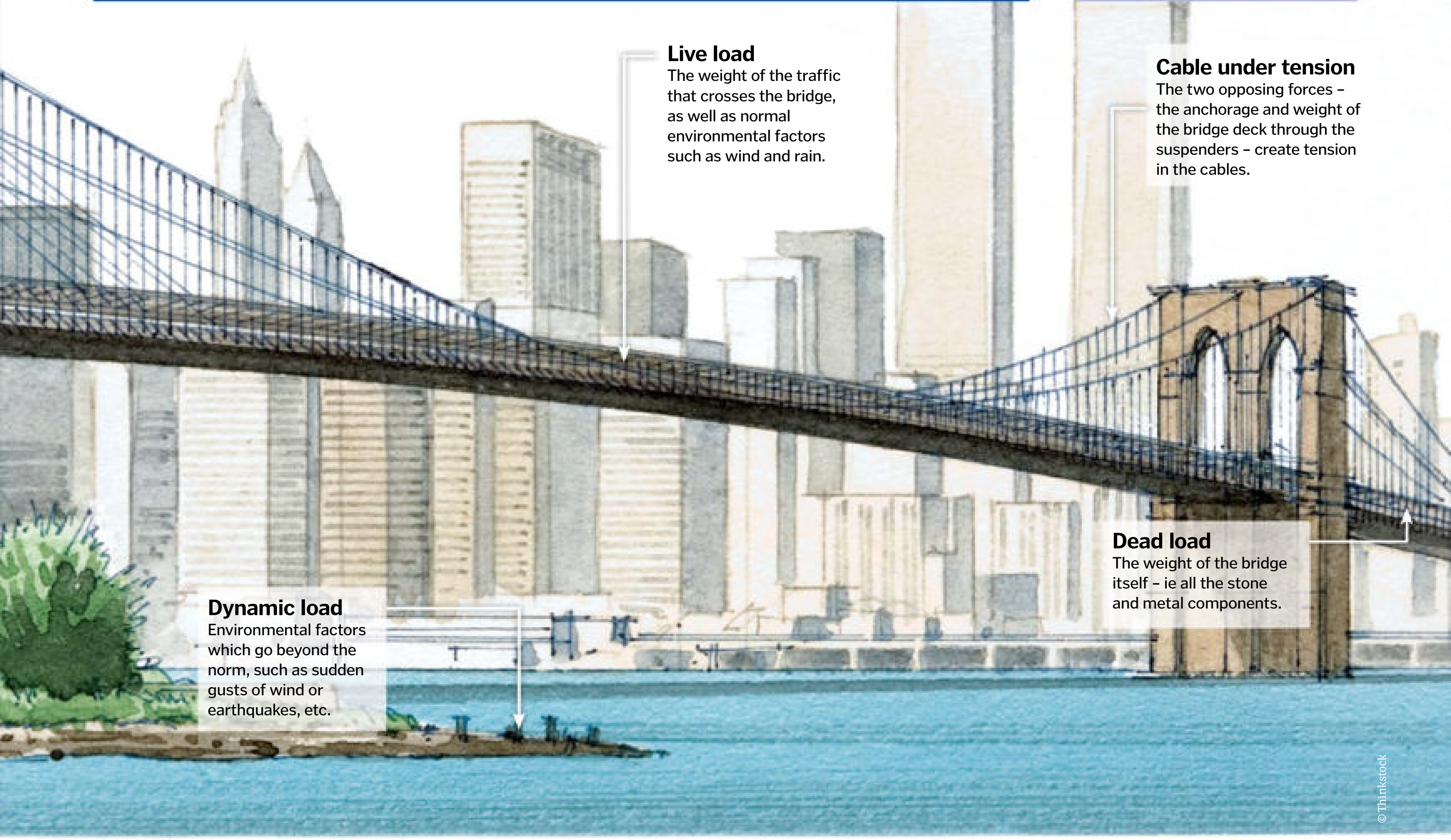
The Brooklyn Bridge during construction in the late-19th century

Cultural impact

Since its completion, the Brooklyn Bridge has inspired many an artist and poet. The modernist American poet Hart Crane, for example, famously published the ode *To Brooklyn Bridge* in 1930. Regarded as a wonder of its age, people flocked to see the structure's opening with a spectacular fireworks display and regatta in 1883 – a celebration which was repeated on its 100th anniversary.

Many people have jumped off the bridge as publicity stunts or suicide attempts, while others have got married on it. In 1919 the Caproni heavy bomber, which was then the world's largest aeroplane, was flown under the deck, while in 2003 it was the intended target of an Al-Qaeda terrorist plot.

The Brooklyn Bridge has also frequently appeared in Hollywood movies, such as *I Am Legend*, *The Dark Knight Rises* and *Godzilla*; more recently the bridge featured in *The Amazing Spider-Man 2.*



Live load
The weight of the traffic that crosses the bridge, as well as normal environmental factors such as wind and rain.

Cable under tension
The two opposing forces – the anchorage and weight of the bridge deck through the suspenders – create tension in the cables.

Dead load
The weight of the bridge itself – ie all the stone and metal components.

Dynamic load
Environmental factors which go beyond the norm, such as sudden gusts of wind or earthquakes, etc.

© Thinkstock

What went wrong at Chernobyl

Learn how a runaway reaction led to a nuclear disaster…

On 25 April 1986, engineers at the nuclear plant at Chernobyl began a test that would lead to the worst nuclear disaster in history. The power plant, located some 130 kilometres (80 miles) north of Kiev, Ukraine, was completed in 1983. Three years later, engineers ran an experiment to see how long the turbines could continue producing energy in the event of a power cut.

The first fatal error made by the technicians that day was to turn off the safety systems. They would have affected the experiment, which involved running the plant at low power, but this action prevented workers realising the dire situation they were soon to put themselves in.

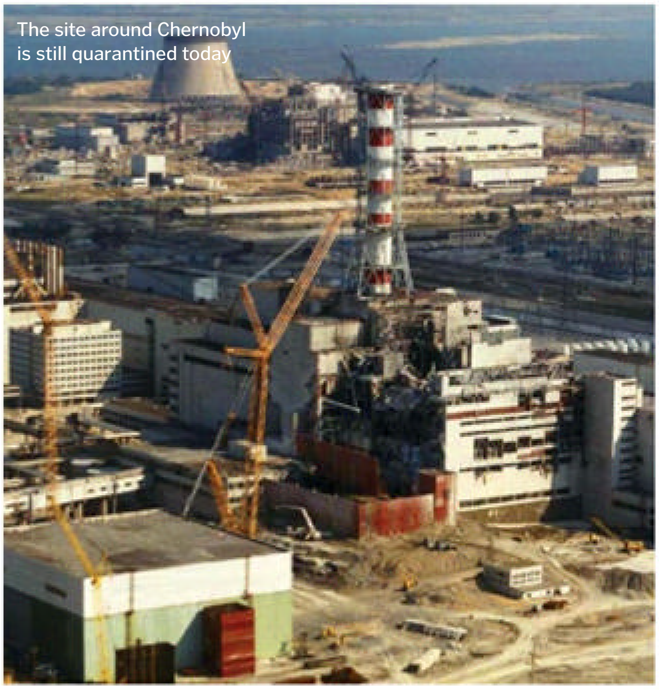
The process of creating nuclear fission is regulated by control rods, which, when inserted into the reactor core, absorb neutrons and slow production. The idea was to lower lots of these rods to reduce the power output and see what happened. Unfortunately, too many were lowered and the output dropped at too high a rate. Rods were then raised again to increase output, returning to about 12 per cent.

However, due to the rods being raised too far and too quickly, a dangerous power surge occurred and the reactor overheated, the water cooling system unable to cope with the sudden demand, turned to steam.

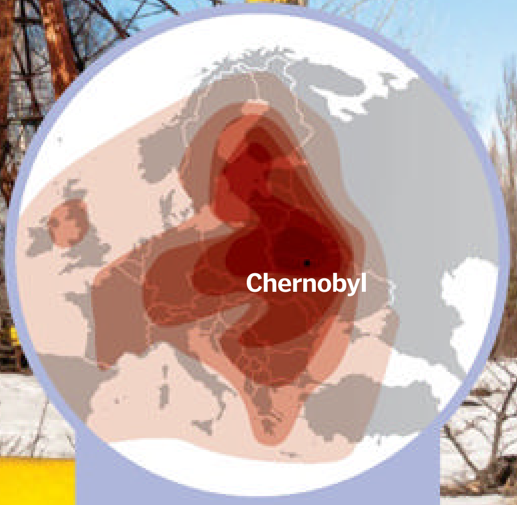
The emergency button was pressed and the rods began to lower but this led to even more rapid reactions in the core.

In the early hours of 26 April, the reactor's roof was blown off and radioactive material began to escape into the atmosphere.

The fire took nine days to extinguish and the radioactive material had far-reaching health and political consequences.



The site around Chernobyl is still quarantined today



Nuclear fallout

The explosion and meltdown was shocking enough, but worse was still to come in the form of radiation spread and health issues for much of Europe.

31 people died immediately after the event with 28 of those deaths a direct result of radiation poisoning inside and around the power plant site.

The worst of the fallout centred around Chernobyl, but increased levels of radiation were detected in areas as far away as the UK, Portugal and Sweden.

Thyroid cancer, caused by the inhalation of contaminated air, has increased tenfold in adolescents in Belarus since 1986 with cases in adults also rising. Cases in children up to the age of 14 also increased, but that number has since reduced due to many of that age group being born after the event.

The impact of the contaminated air has also affected animals, crops and water supplies and the effects are still widely felt to this day. Radiation levels around Chernobyl will remain far higher than average for many millennia.

5 TOP FACTS
CHERNOBYL TRIVIA

Zircaloy rods
1 The control rods were made of neutron absorbing elements, encased in a tube of zircaloy. This was used as it is capable of resisting corrosion by radiation.

Power output
2 The fuel used in Chernobyl was two per cent uranium-235, a frequently-used fission material, and each reactor produced around 1,000MW of energy.

Big bang
3 The buildup of pressure and temperatures of over 2,000°C (3,632°F) caused an explosion that reportedly rose 1,000 metres (3,280 feet) into the air.

Fighting the fire
4 Helicopters doused the flames in boron to slow the nuclear reactions, lead to form a barrier from the radiation and sand to dampen the flames.

Concrete cover-up
5 A reinforced concrete case was constructed around the plant to block radiation. A replacement is currently being built and should be ready in 2015.

DID YOU KNOW? *At least 30 of the 50 rods needed to be inserted to be safe; when the plant exploded only six were inserted*

Countdown to disaster

Find out how history's worst nuclear accident played out

① Safety switches
The safety switches were intentionally turned off to allow the experiment to run without intervention.

② Rods dropped
Control rods were lowered to reduce power output, but the power reduced too much too quickly.

③ Rods raised
In order to get the plant working again, the rods were raised causing a rapid increase in production.

④ Water heating
The all-important cooling water began to overheat, turning to steam and failing to cool the reactor.

⑤ Emergency
Pressing the emergency button lowered the rods again, but they displaced the remaining water.

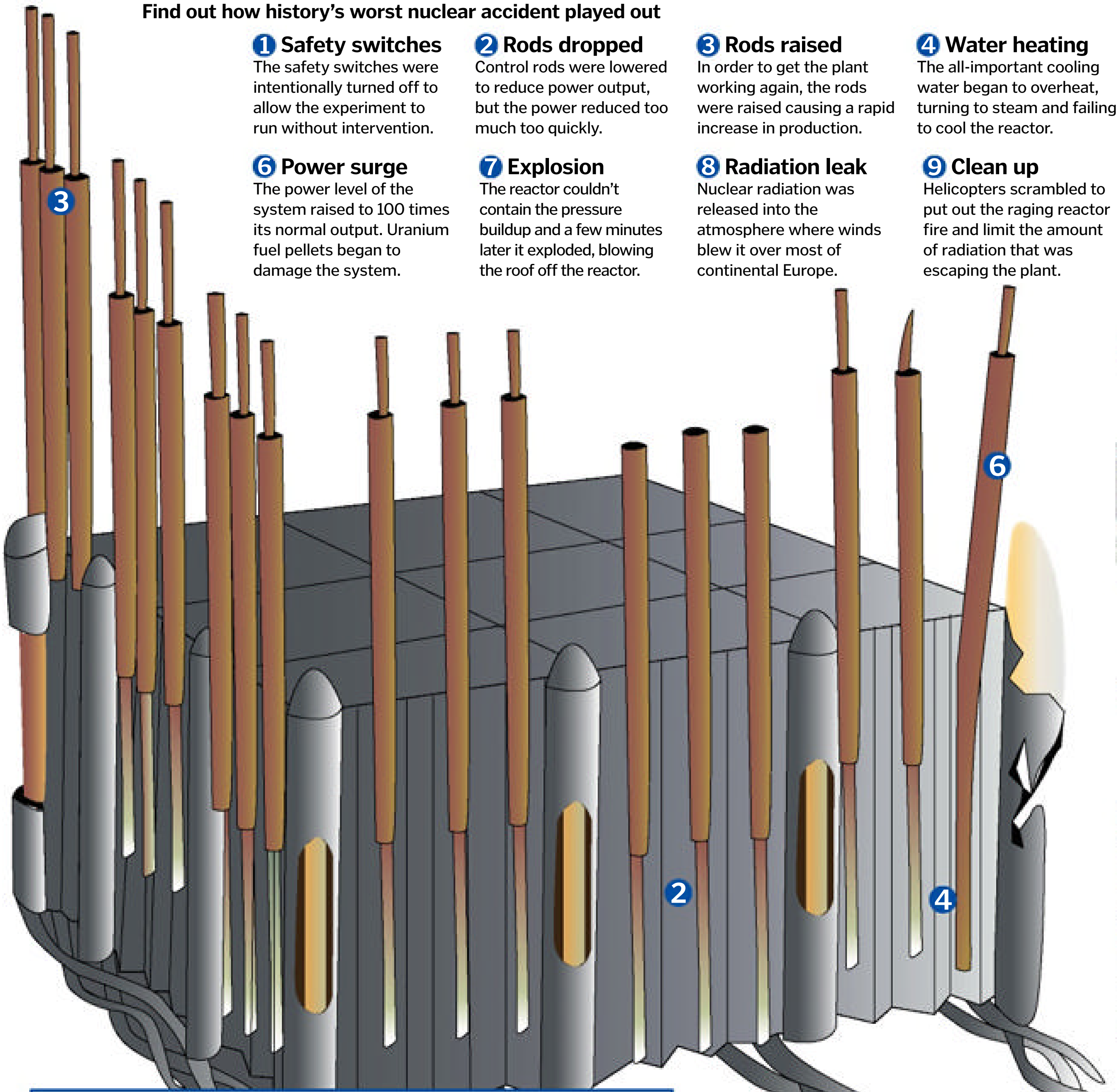
⑥ Power surge
The power level of the system raised to 100 times its normal output. Uranium fuel pellets began to damage the system.

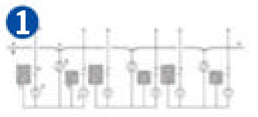
⑦ Explosion
The reactor couldn't contain the pressure buildup and a few minutes later it exploded, blowing the roof off the reactor.

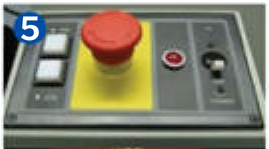
⑧ Radiation leak
Nuclear radiation was released into the atmosphere where winds blew it over most of continental Europe.

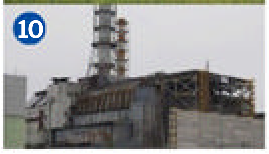
⑨ Clean up
Helicopters scrambled to put out the raging reactor fire and limit the amount of radiation that was escaping the plant.

⑩ Sarcophagus
A concrete shell was hastily constructed and placed over the nuclear plant to limit the release of radiation from Chernobyl.









How it toppled the USSR

The leader of the Soviet Union at the time of the Chernobyl disaster, Mikhail Gorbachev, has claimed that the incident was a key factor in the demise of the USSR.

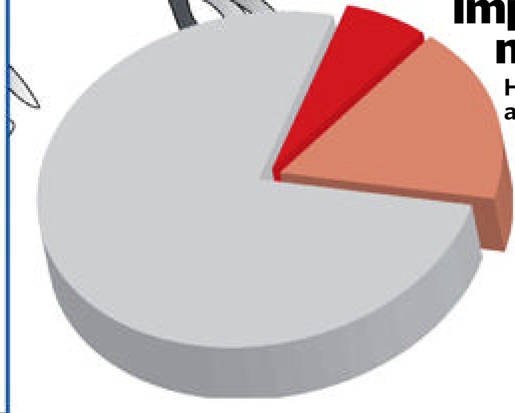
The government's response to the disaster was to try and cover it up as much as possible, with barely any official announcement of it and no warning to residents in the surrounding area as to the dangers of radioactive poisoning. It took a radioactive cloud that passed over Sweden to bring the event to the world's attention.

Furious at the lack of information and protection they had received, especially as Gorbachev had promised a new era of political clarity and honesty, citizens railed against the political system.

The general public lost faith in the government and the government in turn lost control of the general public. Five years later, the Soviet Union was dissolved with Gorbachev quoted as saying, "The nuclear meltdown at Chernobyl […] was perhaps the real cause of the collapse of the Soviet Union."

Impact of the meltdown

How many were directly affected by the disaster?



🟥 **55,000** 6.4% died from radiation

▨ **150,000** 17.4% were left disabled

⬜ **655,000** 76.2% underwent medical supervision

© Corbis; Thinkstock

Exploring Machu Picchu

Perched precariously between two Peruvian peaks, the ancient Incan complex of Machu Picchu is truly one of Earth's wonders

Machu Picchu is a world-famous 15th-century palace complex, at an elevation of 2,430 metres (7,970 feet), built by the Incas. During its heyday it was ruled over by long-reigning king Pachacuti Inca Yupanqui. It is located between the two large mountain peaks of Machu Picchu – which translates as 'Old Peak' – and Huayna Picchu – or 'New Peak' – in the Cuzco region of Peru.

Despite the complex – which consists of over 300 buildings, terraces, plazas and a cemetery – being constructed in the mid-15th to early-16th centuries and well known to the local population, it only gained global fame in 1911, when American archaeologist Hiram Bingham stumbled across it while searching for Vilcabamba – the 'lost city of the Incas'.

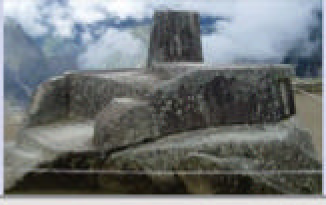
Since its 'discovery' the complex has been extensively excavated as it was in a ruinous and overgrown state and today it is Peru's number one tourist attraction in terms of money generated. While excavations have unearthed lots of unique art, sculpture and architecture, as yet archaeologists are still to determine why the settlement was abandoned. The presence of an extensive aqueduct system throughout the site has led some scholars to believe a climate change-induced lack of water could have been a major factor. ✿

STRANGE BUT TRUE

SUN LOVERS

What did Machu Picchu's Incas use to tie up the Sun?

A A temple **B** A ritual stone **C** A long lasso



Answer:

The Intihuatana ritual stone at Machu Picchu is one of many stones arranged to point at the Sun during the winter solstice. The Incan people believed this stone tied the Sun in place along its annual path in the sky. Its name means 'hitching post of the Sun'.

DID YOU KNOW? *Machu Picchu was made a UNESCO World Heritage Site in 1983*

Machu Picchu
Peru
Brazil

© Thinkstock; Jordan Klein

How was the Sistine Chapel's ceiling painted?

Explore the tools and techniques behind Michelangelo's lofty Renaissance masterpiece

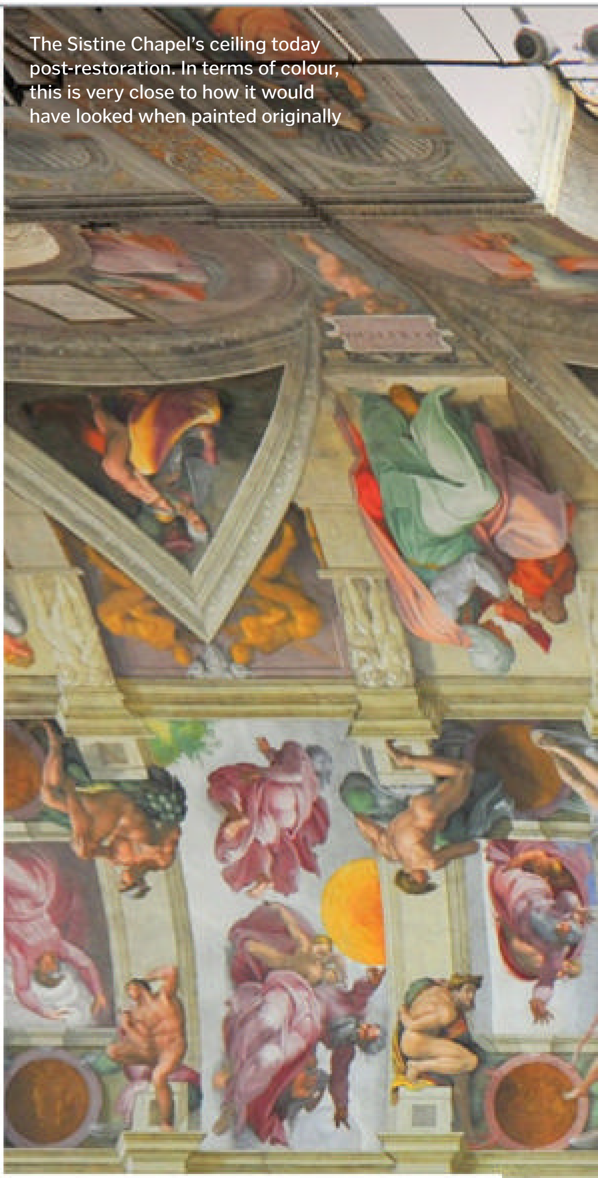
In painting the Sistine Chapel's ceiling in the early part of the 16th century Michelangelo had to overcome a number of daunting hurdles. The first comes directly from the physical properties of the ceiling, as it is a barrel vault, which is a curved surface. To make it more difficult still, that barrel vault is intersected with smaller vaults positioned over the windows. As such there are no flat surfaces anywhere except around the windows, where the artist also painted a series of half-moon-shaped lunettes. As a result, even prior to picking up a paintbrush Michelangelo had to first work out how to create realistic portrayals of human figures in proper proportion and in motion on these wildly uneven surfaces. His ability to pull this off is testament to his immense artistic skill.

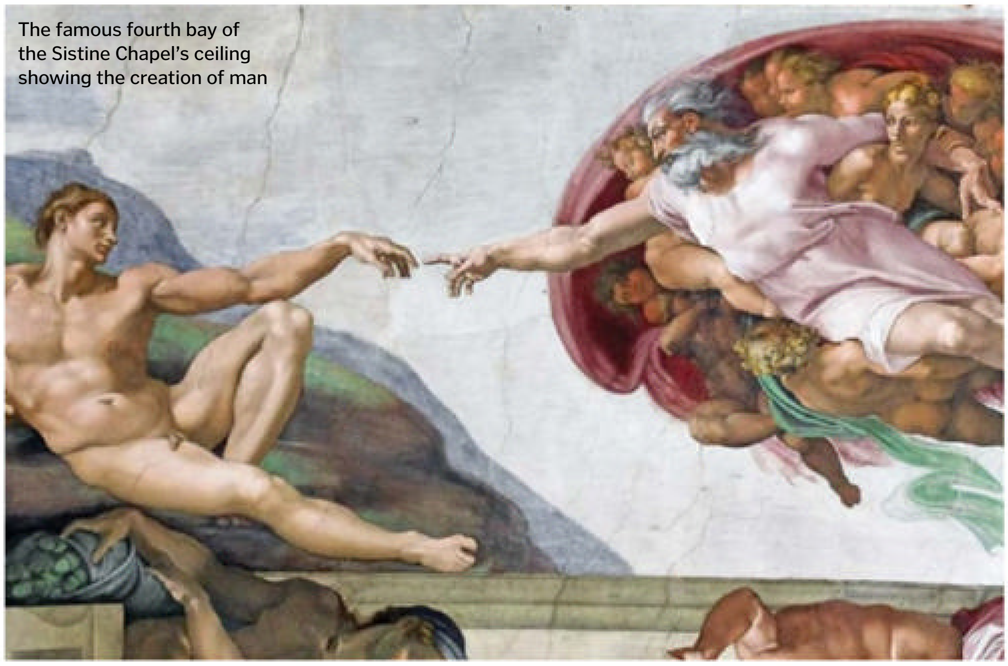
Another major challenge in painting the Sistine Chapel's ceiling was actually getting up there, as it is 20 metres (65 feet) above the floor. Fortunately, a conservation campaign that started in the Eighties revealed the method Michelangelo employed to reach such heights: he constructed a complex scaffold. The scaffold consisted of a truss bridge that spanned across the vault and ran on rails that were at a 90-degree angle to the walls. This permitted Michelangelo to access all areas of the ceiling as the scaffolding could be moved along the rails – it was only ever covering a quarter of the vault at any one time, as he needed ambient light from the windows to paint. Interestingly, the holes that supported this structure can still be seen in the walls to this day.

The third problem Michelangelo had to tackle was how to lay out the sketch lines for the entire ceiling. He did this by dividing the vault into various units by stretching chalked strings from one end of the chapel to the other (with help from assistants), before snapping them against the prepared plaster. In doing this, he laid out the linear structure of all the architecture, which is consistent throughout.

The last major obstacle that Michelangelo faced was the sheer scale of the project, which incredibly only took four years to complete. Painting the ceiling was a massive logistical undertaking and so he invited some of his friends from Florence to Rome to aid him.

As well as painting some of the recurring elements, such as columns and statues, these assistants helped him to build the scaffolding and mix/prepare the plaster, as well as lending a hand with the manufacture of paints, the trimming of paintbrushes and the sketching of full-sized drawings on paper for transferral onto the vault. This latter process involved the paper sketch being pressed against the ceiling, pricked with small holes around the outlines and then covered with black chalk dust to produce a dotted outline on the plaster.


The Sistine Chapel's ceiling today post-restoration. In terms of colour, this is very close to how it would have looked when painted originally


The famous fourth bay of the Sistine Chapel's ceiling showing the creation of man

KEY DATES
SISTINE CHAPEL

1480
Pope Sixtus IV (right) commissions the Sistine Chapel to be constructed.

1508
Michelangelo begins work painting the chapel's ceiling.

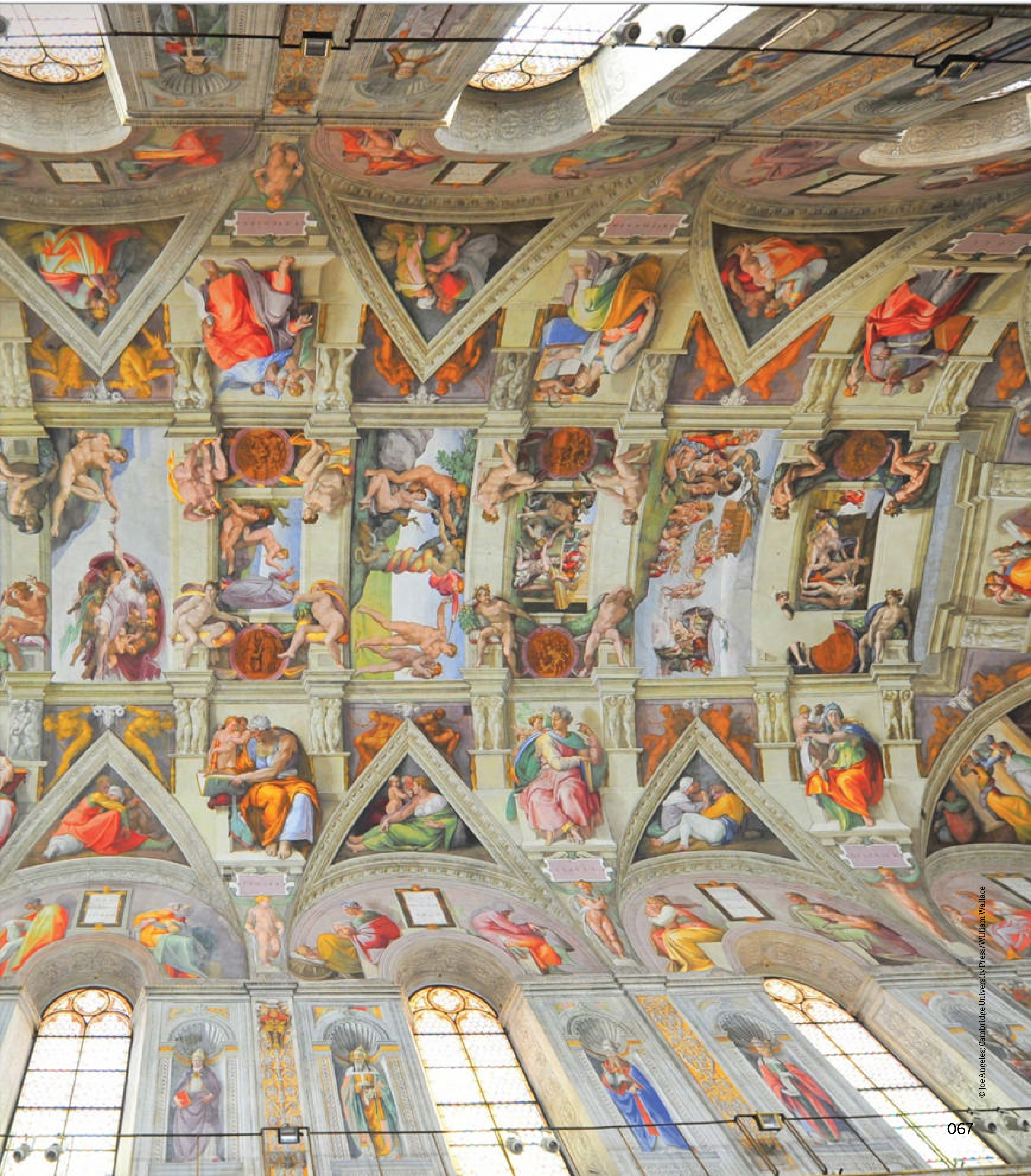
1512
Michelangelo completes his painting of the Sistine Chapel's ceiling (right).

1979
Preliminary analysis and tests are conducted to assess the feasibility of a restoration project.

1984
Restoration of the Sistine Chapel commences.

1994
The Sistine Chapel is finally re-opened to the public post-restoration.

DID YOU KNOW? *Michelangelo is one of many Masters to paint in the Sistine Chapel; others include Botticelli and Pinturicchio*



© Joe Angeles; Cambridge University Press/William Wallace

Cardiff Castle

Why does Wales' most famous fortress look like something from a fairy tale?

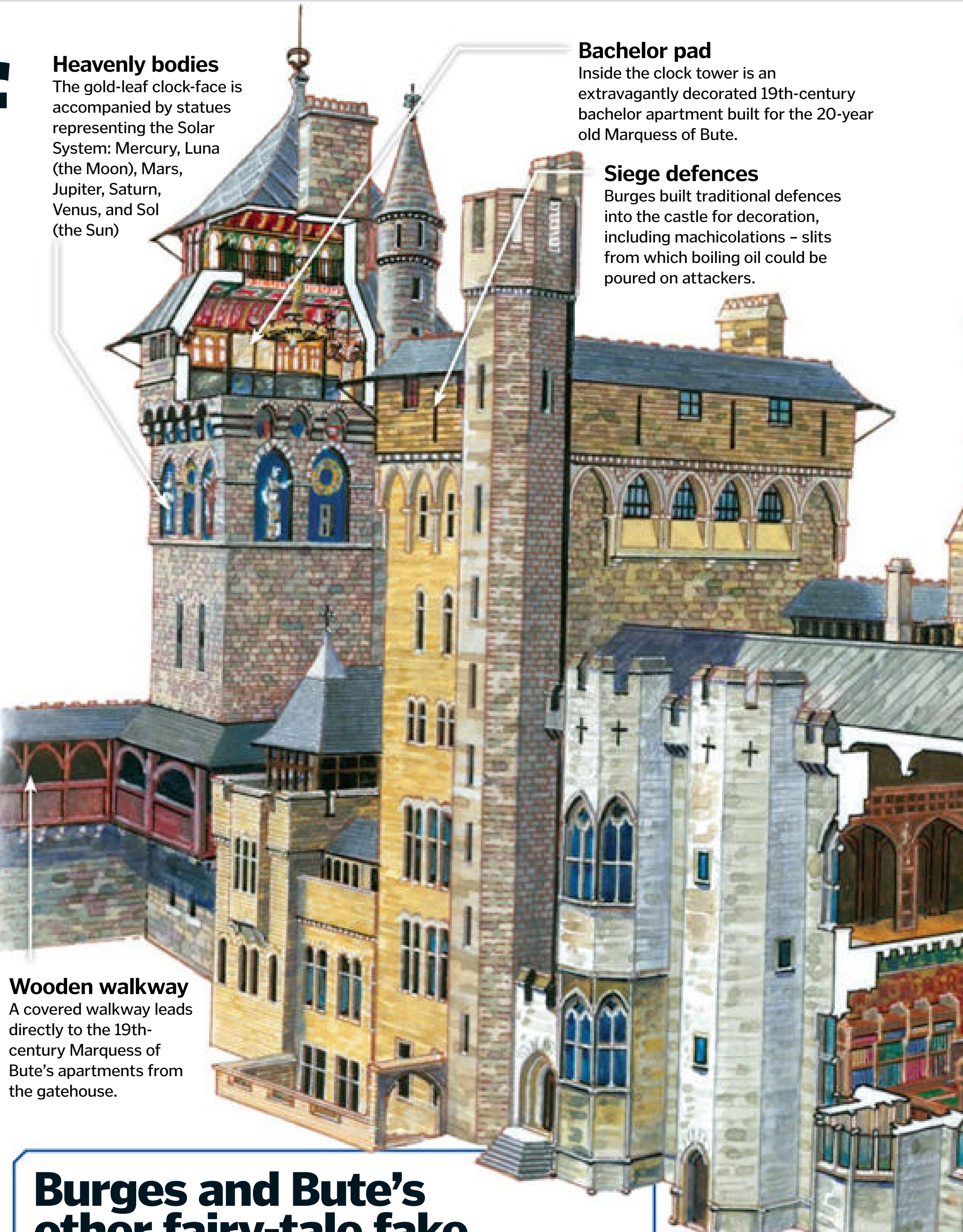
Adorned with elaborate sculptures, covered walkways and dominated by a striking clock tower, Cardiff Castle looks almost too good to be true.

Built sometime after 1081 over the ruins of a Roman fort by the Normans, who were then expanding from England into Wales, Cardiff Castle was extended in the following centuries, notably in the early-15th century, where the keep took shape, and in the 18th century, where it was embellished with a Georgian mansion.

In 1848, Cardiff Castle was inherited by John Patrick Crichton-Stuart, the third Marquess of Bute – then still not six months old – and its story soon took an unexpected swerve into the past. "My luxury is art", wrote Bute later. "I have considerable taste for art and archaeology, and happily the means to indulge them." Armed with his father's wealth and an eclectic taste in history, religion, art, literature and even the occult, the 18-year-old Bute struck up a friendship with eccentric architect and designer William Burges. The two began to rebuild and decorate Cardiff Castle to fit their dream of how a medieval castle should look.

Extensively remodelling the interior with cheeky carvings, stained glass, angelic statues and vaulted ceilings, Burges dwarfed the original building with Bute's new apartments in a 40-metre (130-foot) high clock tower decorated with the symbols of the Zodiac.

Sadly, Burges died in 1881 before his finest work yet – the breathtaking Arab Room, inspired by his travels to Sicily and Turkey – was complete and Bute paid tribute to his "soul-inspiring" friend in marble, carving both of their names where they can still be seen amid the fairy-tale fantasy of Cardiff Castle by stunned visitors today.



Heavenly bodies
The gold-leaf clock-face is accompanied by statues representing the Solar System: Mercury, Luna (the Moon), Mars, Jupiter, Saturn, Venus, and Sol (the Sun)

Bachelor pad
Inside the clock tower is an extravagantly decorated 19th-century bachelor apartment built for the 20-year old Marquess of Bute.

Siege defences
Burges built traditional defences into the castle for decoration, including machicolations – slits from which boiling oil could be poured on attackers.

Wooden walkway
A covered walkway leads directly to the 19th-century Marquess of Bute's apartments from the gatehouse.

Burges and Bute's other fairy-tale fake

Burges and Bute didn't leave it at the one castle; they built a whole new one almost entirely from scratch in Tongwynlais, north of Cardiff, which was to serve as the Marquess' summer home.

After clearing the weeds and debris away from the ruins of the 13th-century Castell Coch (Welsh for 'Red Castle') in 1871, construction began in 1875 and Burges 'rebuilt' the castle with three historically dubious coned towers and covered wooden walkways that would look more at home in Central Europe. That Southern Wales.

Once past the portcullis and drawbridge, the interiors match Cardiff Castle for ostentation and Castell Coch has been used by TV series such as *Merlin*, *Doctor Who*, and *Da Vinci's Demons*. A 1954 *Welsh Office Official Handbook* describes Castell Coch as a "gigantic sham, a costly folly erected by an eccentric Victorian architect to satisfy the antiquarian yearnings of a wealthy nobleman." Ouch!

5 TOP FACTS
BURGES BUILDINGS

Worcester College, Oxford
1 Burges overhauled the 18th-century hall and chapel in 1864, adding carved animals and mosaics. Most of his work was removed in the 1960s.

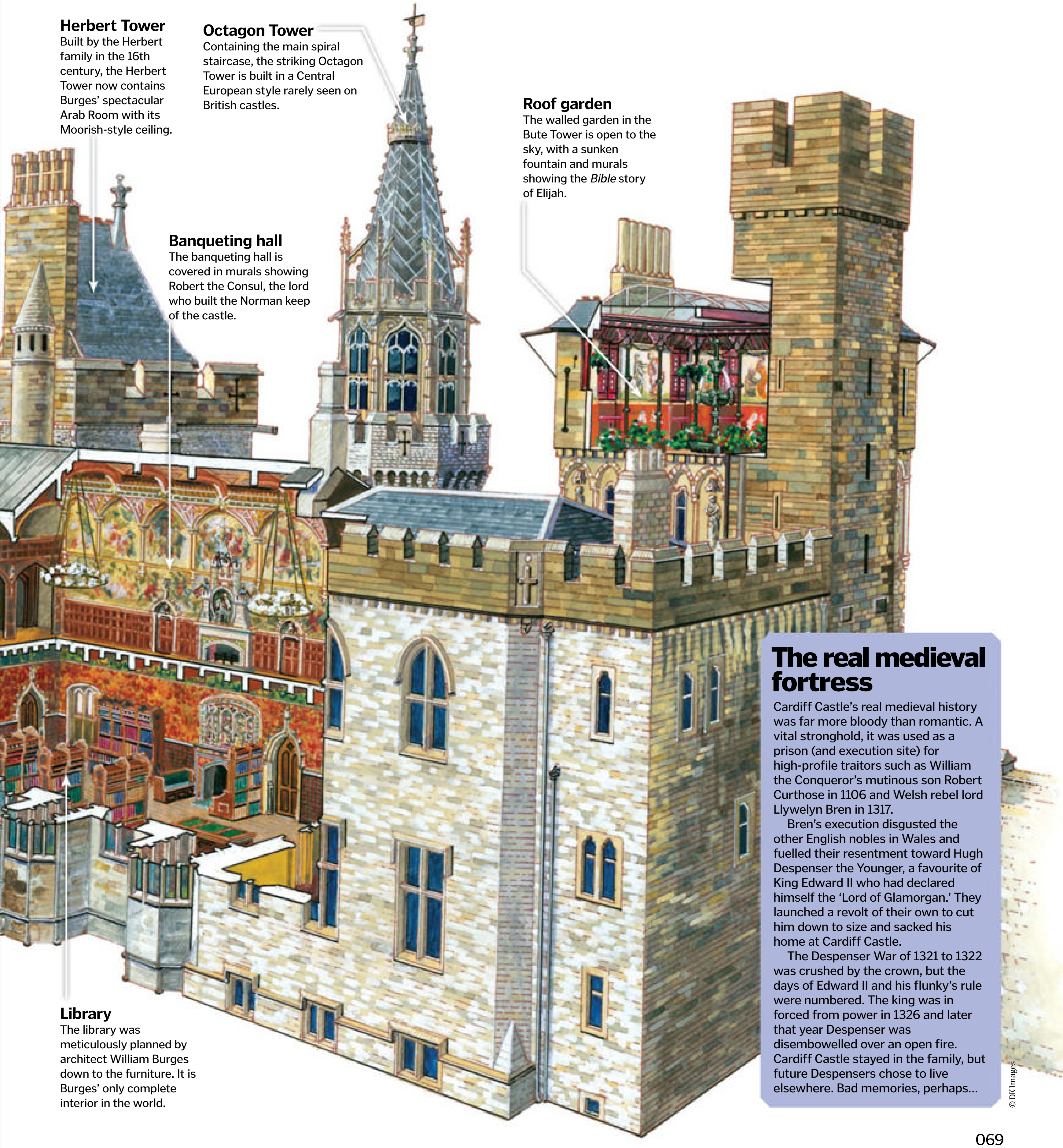
Knightshayes Court, Devon
2 He designed a new mansion for businessman and politician John Heathcoat-Amory, remarkable because it was the only conventional home he built.

Saint Fin Barre's Cathedral, Ireland
3 Burges' first major work, Saint Fin Barre's Cathedral is a graceful Gothic church that earned the architect a prize of £100.

Waltham Abbey, Essex
4 Restoring and remodelling the interior in 1876, Burges painted the ceiling with the signs of the Zodiac, something he later repeated at Cardiff Castle.

Mount Stuart House, Isle of Bute
5 The Marquess of Bute's family home was rebuilt by Burges in Gothic style. Mount Stuart was the first house to feature a heated swimming pool.

DID YOU KNOW? One outside wall is decorated with 15 different animals – many were recarved because they weren't fierce enough



Herbert Tower
Built by the Herbert family in the 16th century, the Herbert Tower now contains Burges' spectacular Arab Room with its Moorish-style ceiling.

Octagon Tower
Containing the main spiral staircase, the striking Octagon Tower is built in a Central European style rarely seen on British castles.

Roof garden
The walled garden in the Bute Tower is open to the sky, with a sunken fountain and murals showing the *Bible* story of Elijah.

Banqueting hall
The banqueting hall is covered in murals showing Robert the Consul, the lord who built the Norman keep of the castle.

Library
The library was meticulously planned by architect William Burges down to the furniture. It is Burges' only complete interior in the world.

© DK Images

The real medieval fortress

Cardiff Castle's real medieval history was far more bloody than romantic. A vital stronghold, it was used as a prison (and execution site) for high-profile traitors such as William the Conqueror's mutinous son Robert Curthose in 1106 and Welsh rebel lord Llywelyn Bren in 1317.

Bren's execution disgusted the other English nobles in Wales and fuelled their resentment toward Hugh Despenser the Younger, a favourite of King Edward II who had declared himself the 'Lord of Glamorgan.' They launched a revolt of their own to cut him down to size and sacked his home at Cardiff Castle.

The Despenser War of 1321 to 1322 was crushed by the crown, but the days of Edward II and his flunky's rule were numbered. The king was forced from power in 1326 and later that year Despenser was disembowelled over an open fire. Cardiff Castle stayed in the family, but future Despensers chose to live elsewhere. Bad memories, perhaps...

WEAPONS & WAR

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Discover the fastest British tank

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Why has trench warfare come to define WWI?

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Step into the aircraft that trained pilots for WWII

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How this famous tank led the Allied war machines in WWII

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How were these powerful siege engines built and used?

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What made the Zulu warriors so successful?

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The origins of this popular military unit

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The most famous conflict of the Hundred Years' War

092 **The A7V**
How this German tank was built and operated

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Learn about what gunpowder is and how it was made

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How were horses protected during battles?

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One of the most iconic fighter planes ever built

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The intricacies of this martial sport of the Middle Ages

098 **How drawbridges worked**
The key mechanisms of these fold-up entrances

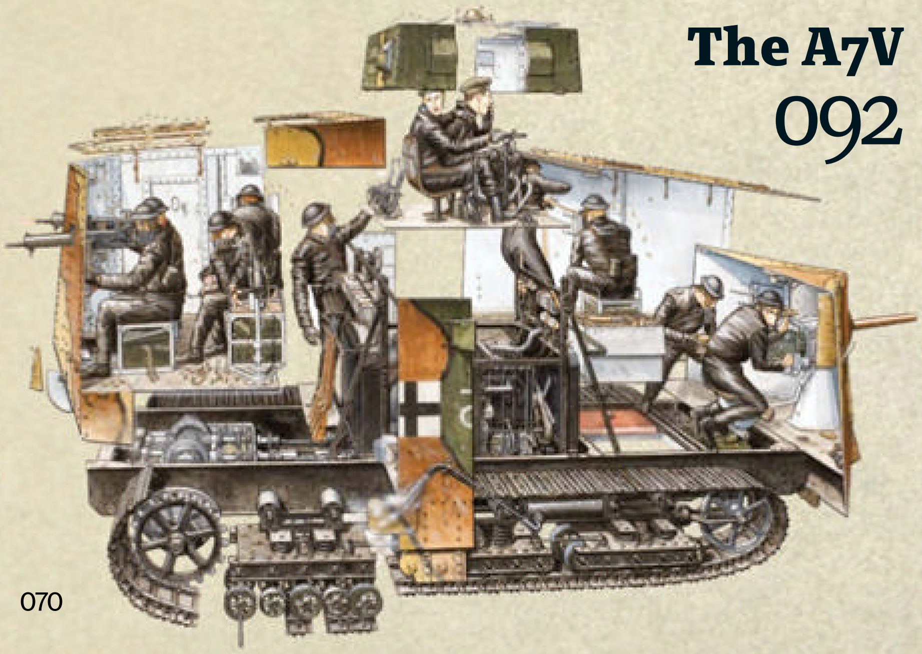
099 **Flint weapons**
Look into the world of the weapons before metal

099 **Breaking the sound barrier**
How does a whip break the sound barrier?

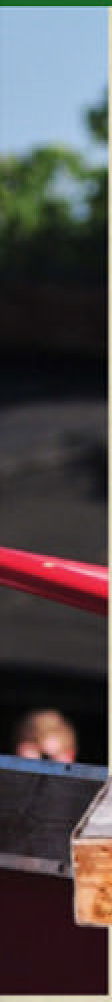
096 **Jousting explained**

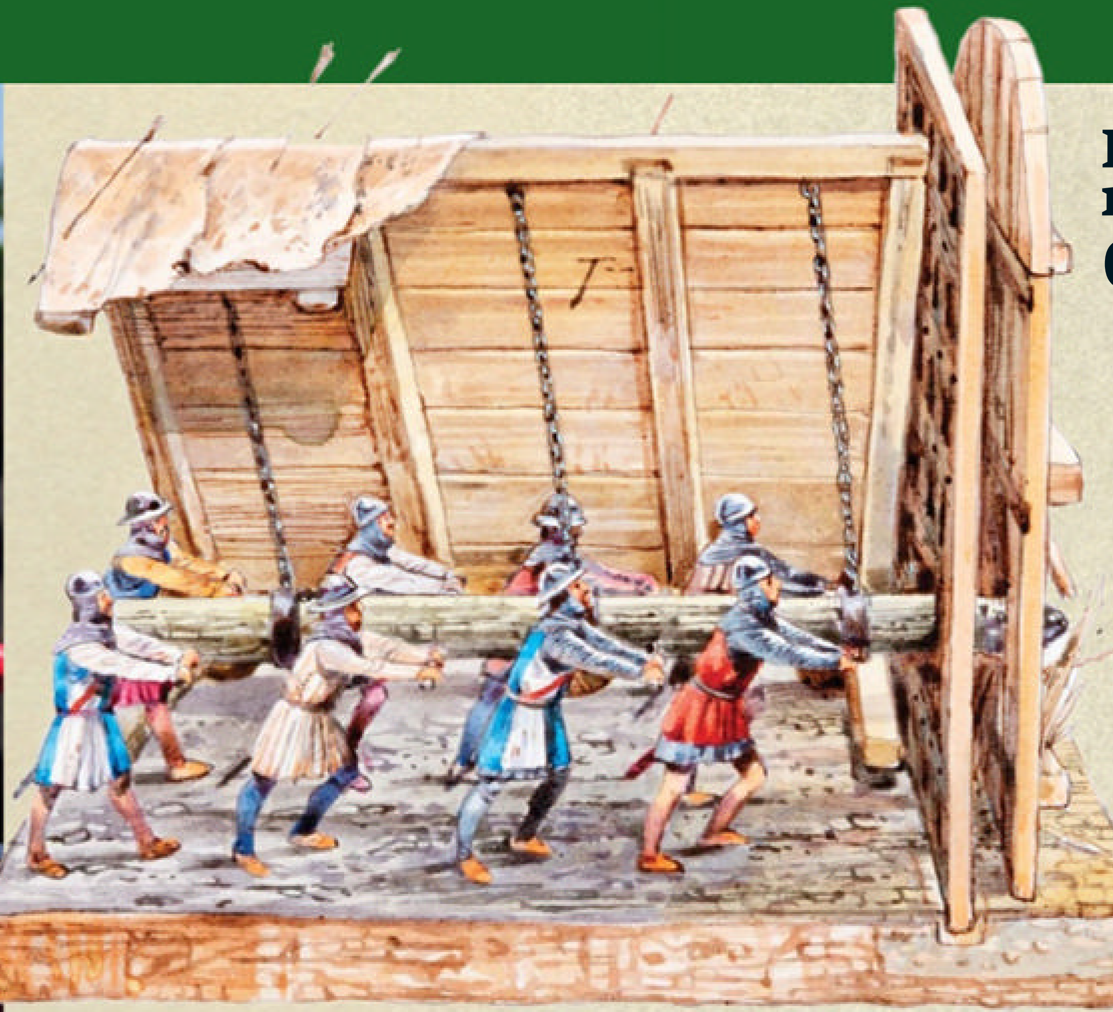
FOUCONBERG
DAMMARTIN
BAR
D'ALENCON
D'ALBERT
YORK
ERPINGHAM
AGINCOURT

088 **Battle of Agincourt**



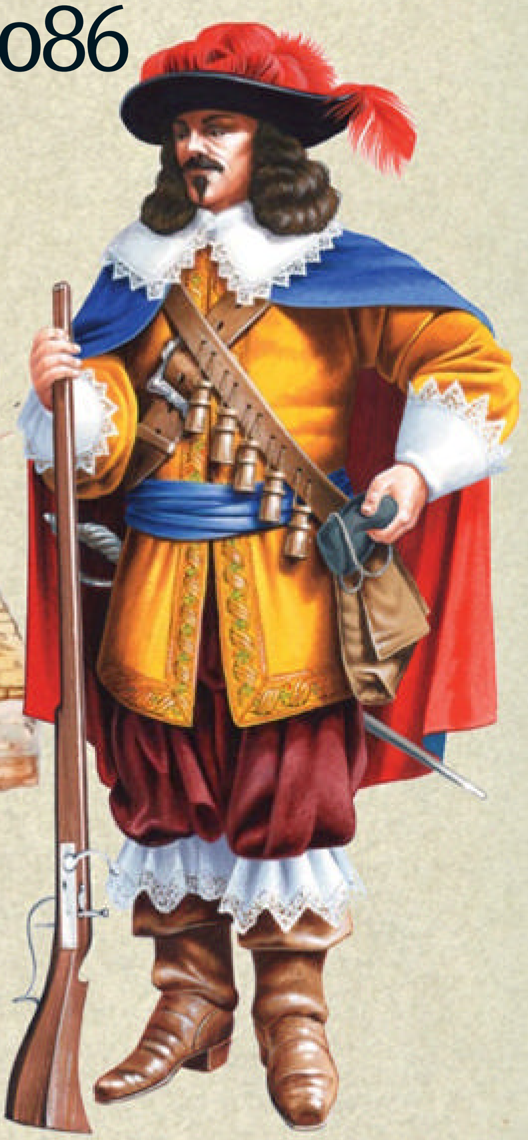
The A7V 092





Meet the musketeers

086



Battering rams

084

How does gunpowder work?

094

CAMOYS
TRAMECOURT
HENRY
ENGLAND
MAISCONCEUES

RCAF 422
RCAF 242
46
AJ583
54
3830

Fly a WWII plane

078

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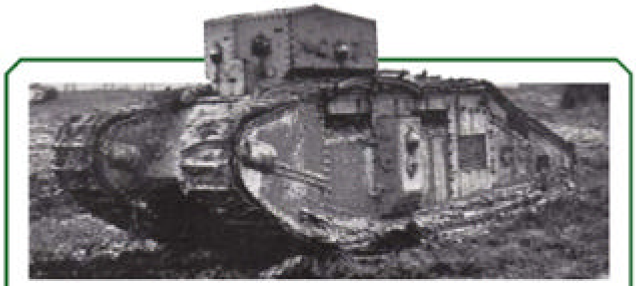
Inside a Whippet tank

The fastest British tank of WWI, the Whippet was a deadly mobile gun nest

The only British medium tank to see action in World War I, the Medium Mark A – later known as the Whippet – was proposed by businessman William Tritton on 3 October 1916 and developed by his chief engineer, William Rigby. Tritton, along with Lieutenant Walter Wilson, was the inventor of the Mark I heavy tank and the Little Willie prototype, and he saw a gap in the battlefield for something faster than the Mark I's less-than-impressive top speed of 5.9 kilometres (3.7 miles) per hour.

Able to hit 12.9 kilometres (eight miles) per hour the Medium A wasn't the hammer that delivered the battlefield's killing blow like the Mark I, but was designed to be more of a chisel, able to force open the weak points already subject to infantry assault, artillery bombardment or assault from the heavier models. While the Mark I's main weapons were its two six-pounder naval guns, the Whippet relied on four machine guns mounted on its fixed turret, which proved devastating to infantry caught in the open.

On 24 April 1918 just seven tanks ambushed two German infantry battalions near Cachy in Northern France and killed over 400 men. In another incident that proved just how devastating these fast-moving machine-gun nests could be, a single Medium A – called Musical Box by its crew – advanced so far on 8 August 1918 that it was completely cut off. Musical Box spent nine hours rampaging behind the German lines, destroying an artillery battery, an observation balloon, the camp of an infantry battalion and raiding a column of German infantry before bullets pierced a petrol can, causing fuel to leak and fill the cabin with fumes. Fighting on in their gas masks, a field gun finally disabled the tank. Amazingly, two of the three crewmen survived and were taken prisoner.

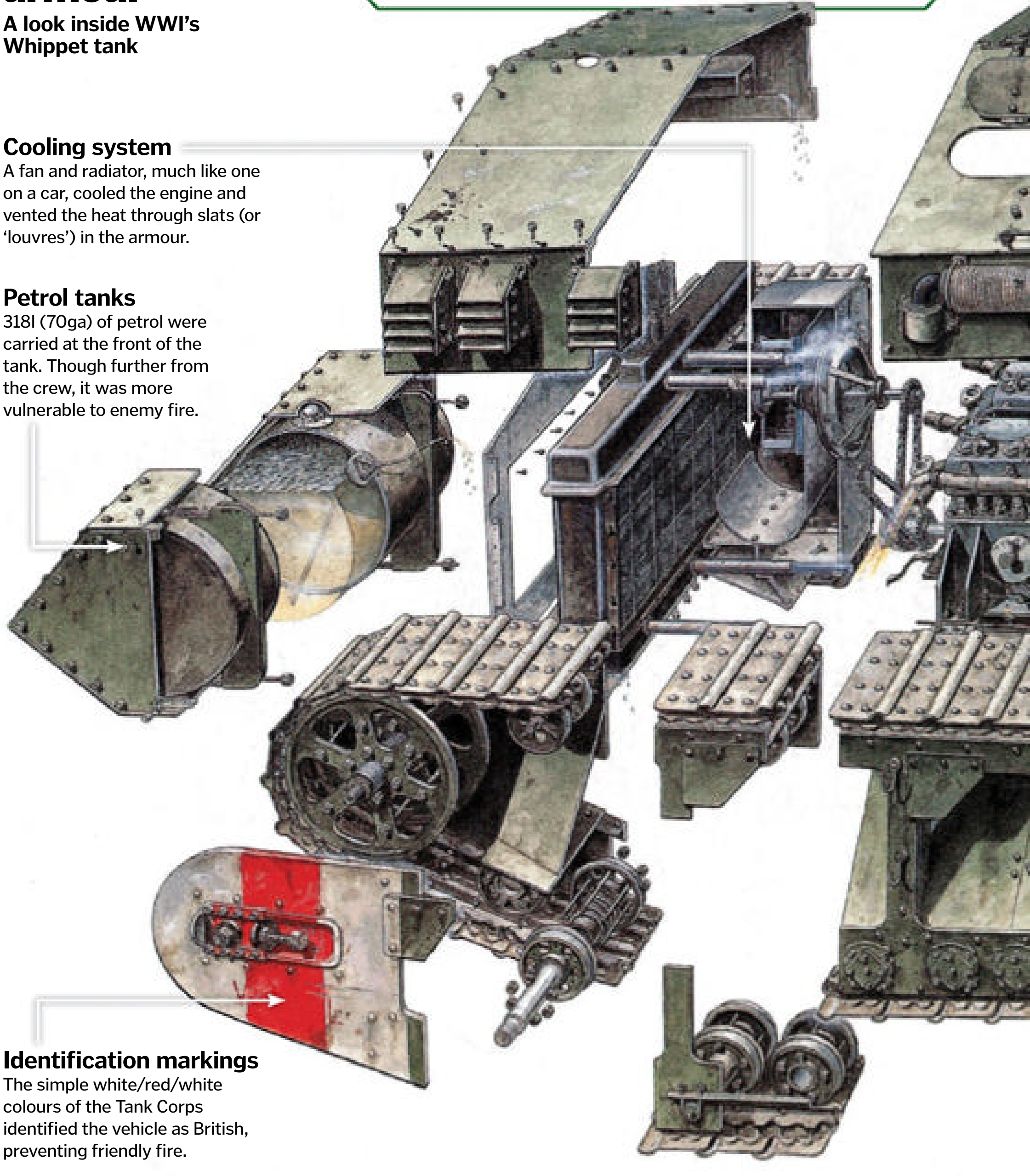


Son of Whippet

Mark I co-creator Walter G Wilson had been left out of Tritton's Medium A project and thought he could do better. The Medium B's real innovations was the sloped armour at the front of the hull, the ability to lay a smoke screen and having the crew in a separate compartment from the engine – all now standard features in tank design. The first prototype was ready in September 1918, but the end of the war on 11 November 1918 led to the order being cancelled with only 100 tanks in service. Confusingly enough, the Medium B was also called Whippet.

Behind the armour

A look inside WWI's Whippet tank



Cooling system
A fan and radiator, much like one on a car, cooled the engine and vented the heat through slats (or 'louvres') in the armour.

Petrol tanks
318l (70ga) of petrol were carried at the front of the tank. Though further from the crew, it was more vulnerable to enemy fire.

Identification markings
The simple white/red/white colours of the Tank Corps identified the vehicle as British, preventing friendly fire.

THE STATS

WHIPPET STATS

PRODUCED 1917-18

WEIGHT 14 tons

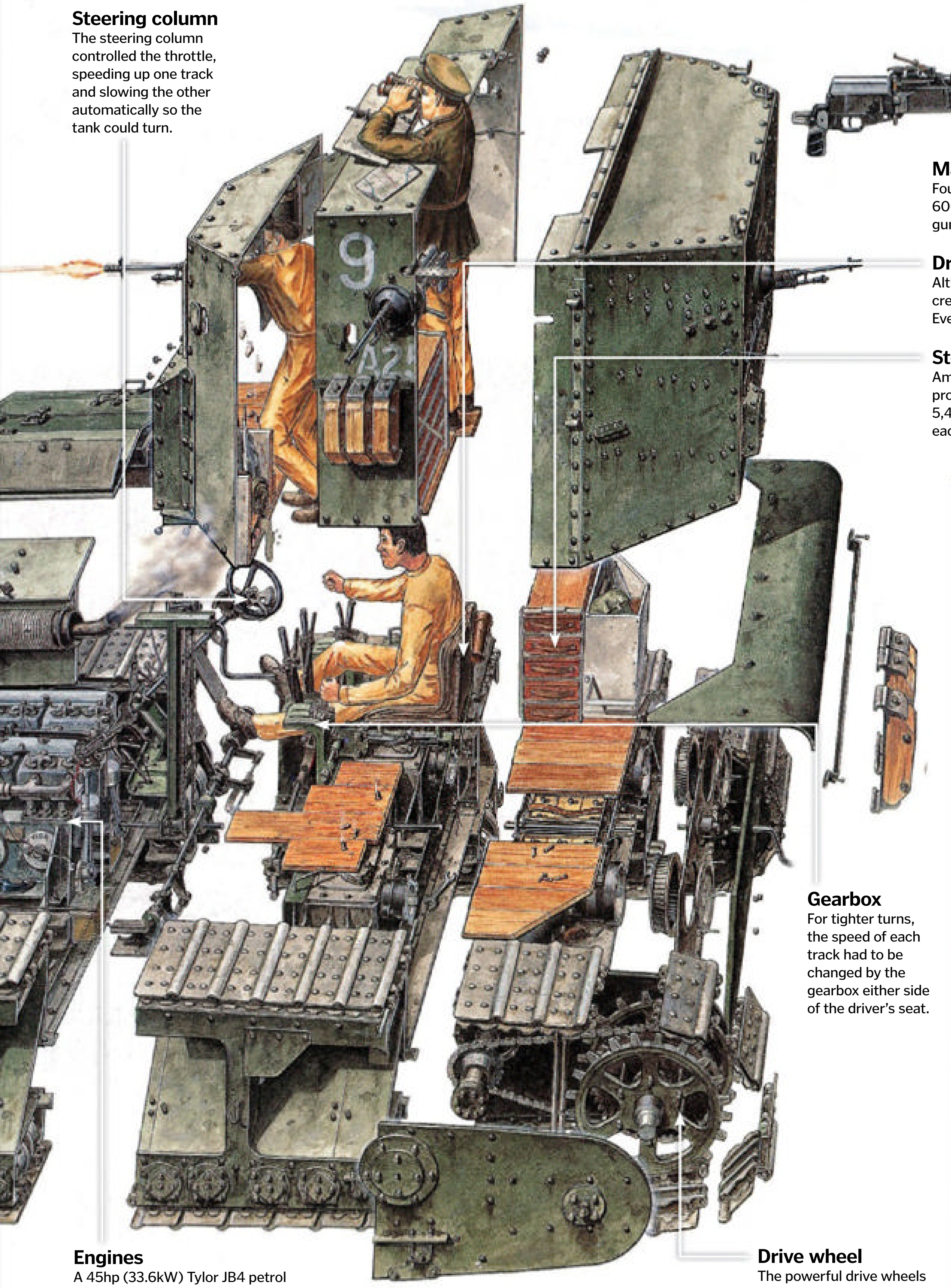
HEIGHT 2.75m (9ft)

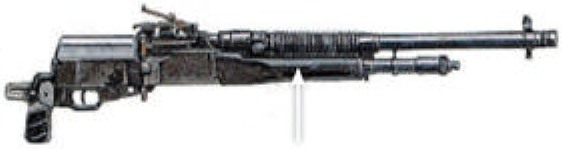
LENGTH 6.1m (20ft)

ARMOUR THICKNESS 14mm (0.55in)

WIDTH 2.62m (8.6ft)

DID YOU KNOW? *A small number of Whippets were sold to Japan and were used as late as the 1930s*





Steering column

The steering column controlled the throttle, speeding up one track and slowing the other automatically so the tank could turn.

Machine guns

Four Hotchkiss machine guns, firing up to 600 rounds per minute. There was only one gunner so he had to jump between guns.

Driver's seat

Although the Whippet typically had three crewmen, there was only seat for the driver. Everyone else had to crouch awkwardly.

Storage

Ammunition racks and a metal stowage bin provided the tank's only storage. Around 5,400 rounds of ammunition were carried in each tank.

Gearbox

For tighter turns, the speed of each track had to be changed by the gearbox either side of the driver's seat.

Engines

A 45hp (33.6kW) Tylor JB4 petrol engine drove each track. In peacetime, they were commonly used on London double-decker buses.

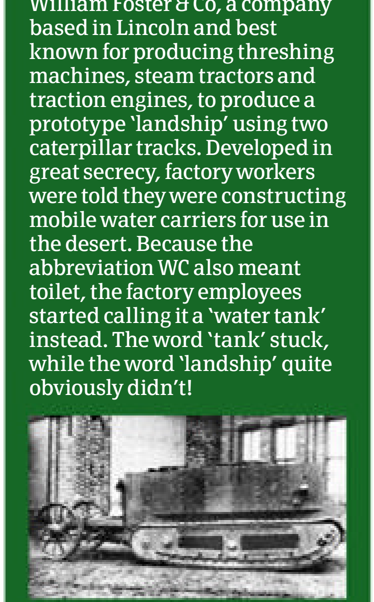
Drive wheel

The powerful drive wheels at the rear of the tank pulled the tracks over 16 small road wheels.

The birth of the tank

The tank emerged out of a need for an armoured vehicle that could traverse the muddy terrain of the Western Front of World War I. The army weren't interested, but the First Lord of the Admiralty – future British Prime Minister Winston Churchill – saw potential in the idea and adopted it as a Royal Navy project, forming the Landships Committee in February 1915.

A contract was put out to William Tritton, chairman of William Foster & Co, a company based in Lincoln and best known for producing threshing machines, steam tractors and traction engines, to produce a prototype 'landship' using two caterpillar tracks. Developed in great secrecy, factory workers were told they were constructing mobile water carriers for use in the desert. Because the abbreviation WC also meant toilet, the factory employees started calling it a 'water tank' instead. The word 'tank' stuck, while the word 'landship' quite obviously didn't!



The first tank prototype, Little Willie

© DK Images

Life in the trenches

Why has trench warfare come to define WWI?

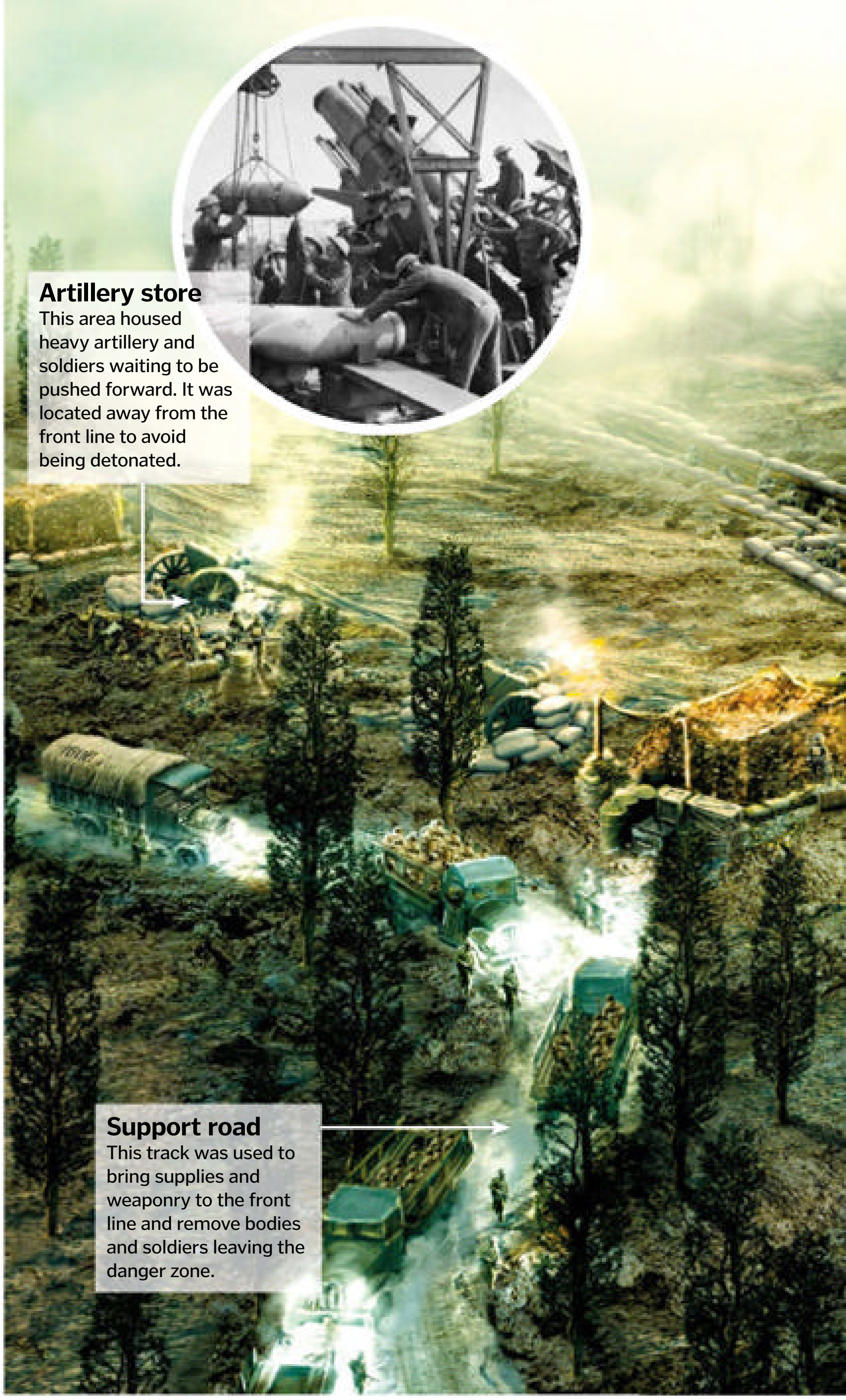
World War I represented a major shift in warfare practice. Aircraft and machine guns were two examples, but what truly dictated this conflict was trench warfare.

The first trenches of note were dug by Germans in September 1914 after their charge through France was halted by Allied forces. In order to avoid losing ground, they dug in, creating deep crevasses to hide in. The Allies quickly realised they couldn't breach these defences and followed suit. What ensued was a race to outflank the opponent along northern France. The first trenches were fairly shallow ditches, but evolved into an elaborate system of frontline trenches, support trenches and barbed wire fences.

It would take 450 men six hours to construct a trench of just 250 metres (820 feet), after which sandbags, wooden walkway planks and barbed wire needed to be strategically placed to stop flooding, collapsing and enemy advances. They were dug in zigzag patterns to stop enemies taking out an entire group of soldiers in one attack. The most time-effective method of trench digging was standing on the ground and digging downward, but that left soldiers at the mercy of enemy fire. The alternative was to dig down then along, while still in the hole. This was safer but much slower.

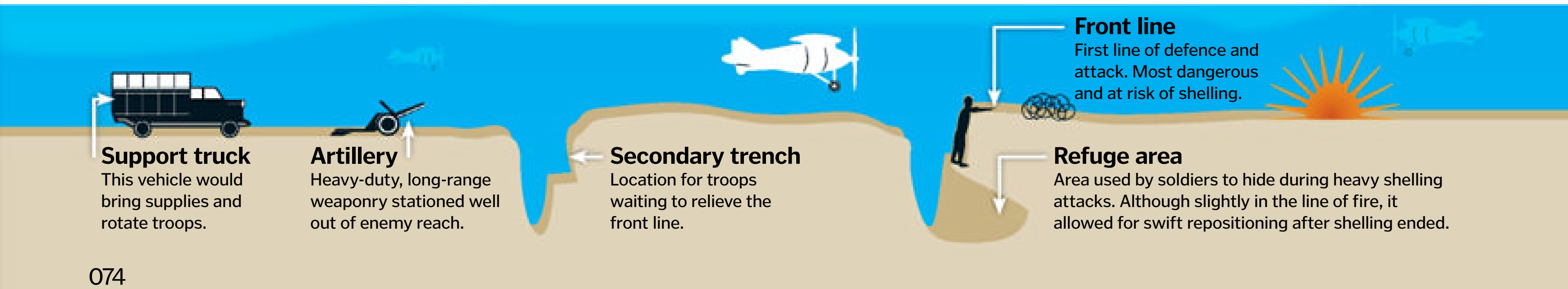
WWI battlefield revealed

See how the complex trench system was laid out



Artillery store
This area housed heavy artillery and soldiers waiting to be pushed forward. It was located away from the front line to avoid being detonated.

Support road
This track was used to bring supplies and weaponry to the front line and remove bodies and soldiers leaving the danger zone.



Front line
First line of defence and attack. Most dangerous and at risk of shelling.

Support truck
This vehicle would bring supplies and rotate troops.

Artillery
Heavy-duty, long-range weaponry stationed well out of enemy reach.

Secondary trench
Location for troops waiting to relieve the front line.

Refuge area
Area used by soldiers to hide during heavy shelling attacks. Although slightly in the line of fire, it allowed for swift repositioning after shelling ended.

KEY DATES
WWI MILESTONES

Sept 1914
Allied resistance at Marne forces the advancing German army to dig trenches.

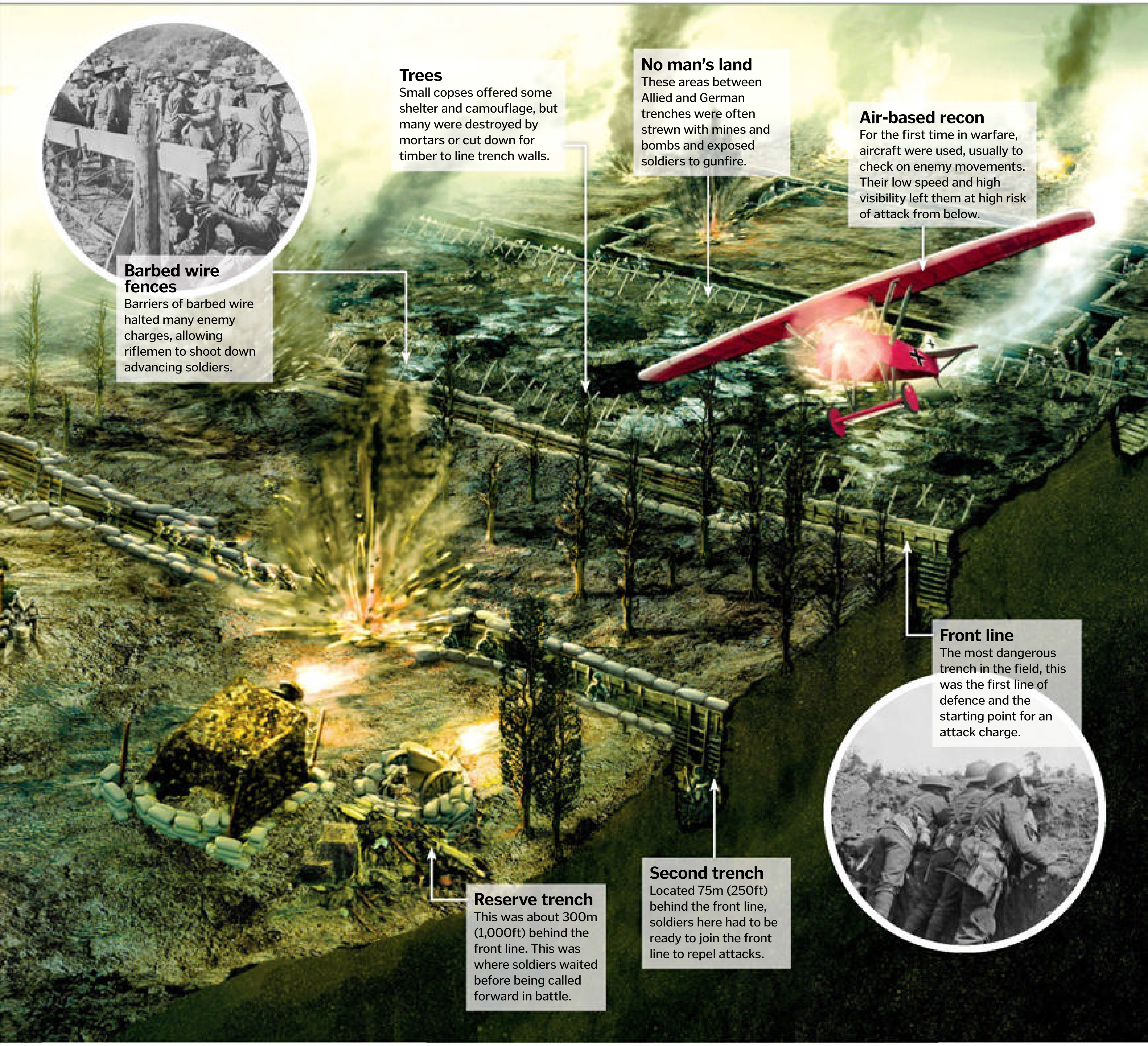
Nov 1914
The first Battle of Ypres in Flanders draws to a close, resulting in a victory for the Allies.

Jul 1916
The devastating Battle of the Somme results in heavy casualties on both sides.

Apr 1917
British and Canadian forces take Vimy Ridge near the town of Arras in northern France.

Oct 1918
Allies break through the so-called Hindenburg Line, gaining a war-ending victory.

DID YOU KNOW? *Around 140,000 Chinese labourers fought in Allied trenches during World War I*



Barbed wire fences
Barriers of barbed wire halted many enemy charges, allowing riflemen to shoot down advancing soldiers.

Trees
Small copses offered some shelter and camouflage, but many were destroyed by mortars or cut down for timber to line trench walls.

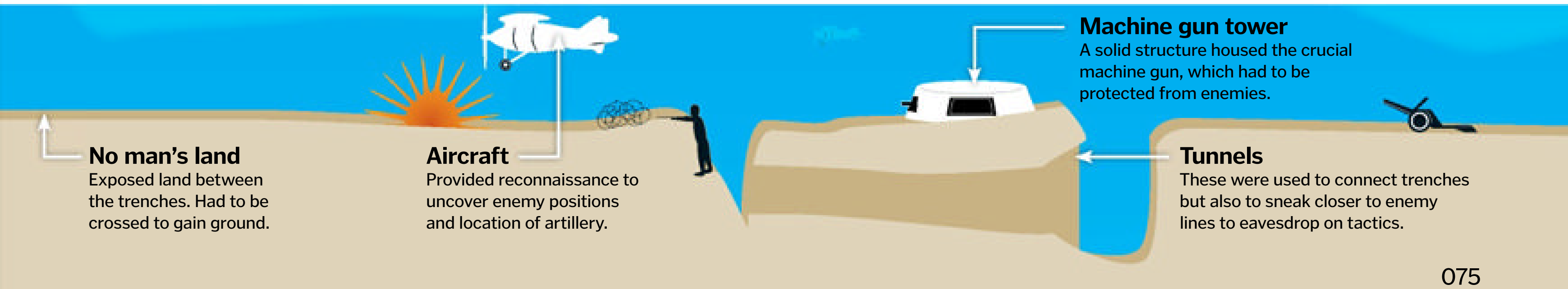
No man's land
These areas between Allied and German trenches were often strewn with mines and bombs and exposed soldiers to gunfire.

Air-based recon
For the first time in warfare, aircraft were used, usually to check on enemy movements. Their low speed and high visibility left them at high risk of attack from below.

Front line
The most dangerous trench in the field, this was the first line of defence and the starting point for an attack charge.

Reserve trench
This was about 300m (1,000ft) behind the front line. This was where soldiers waited before being called forward in battle.

Second trench
Located 75m (250ft) behind the front line, soldiers here had to be ready to join the front line to repel attacks.



Machine gun tower
A solid structure housed the crucial machine gun, which had to be protected from enemies.

No man's land
Exposed land between the trenches. Had to be crossed to gain ground.

Aircraft
Provided reconnaissance to uncover enemy positions and location of artillery.

Tunnels
These were used to connect trenches but also to sneak closer to enemy lines to eavesdrop on tactics.

Located in north-east France, Marne was the site of the war's first example of trench warfare. German and Allied forces both realised the defensive power of this strategy so engaged in a shovelling 'Race to the Sea', building trenches all the way to the North Sea at Ypres, Belgium.

This then became the location for a bed-in that lasted for the remainder of the war, with attacks and counterattacks barely gaining any ground at all, but at the cost of millions of lives.

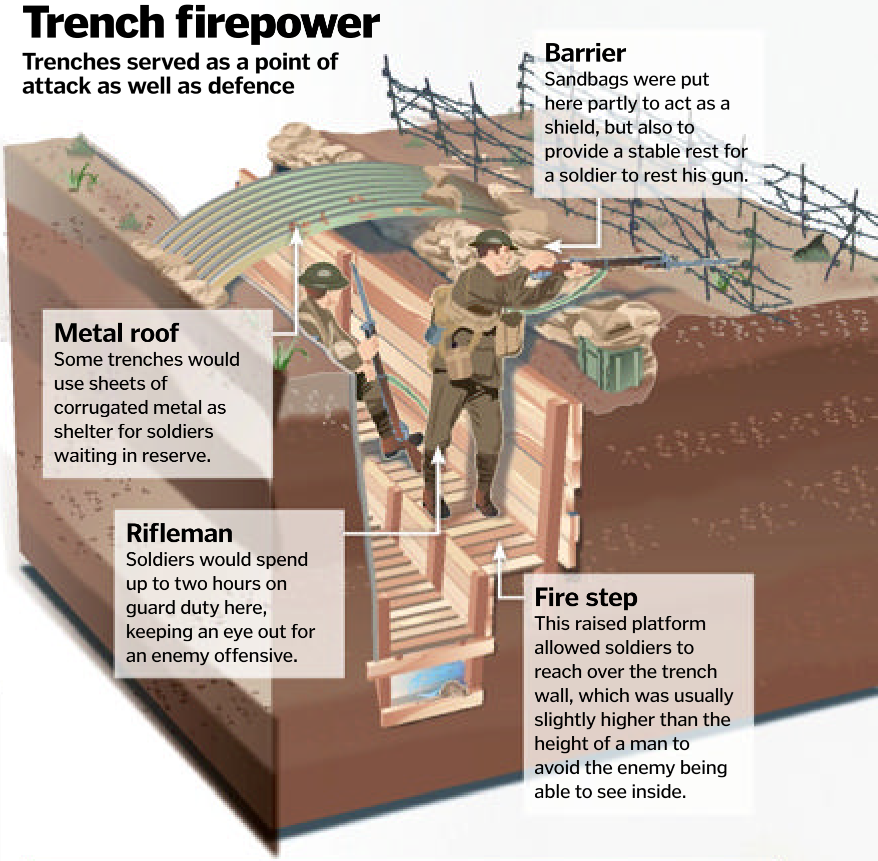
Verdun was another bloody site, with the Germans launching a devastating attack on the fortified town. They broke French resistance but the counter-offensive eventually drove them back to their starting point, resulting in a similarly prolonged trench standoff.

The German forces failed to conquer Verdun because they had to focus on the British army's assault on the Somme. This began with a massive week-long bombardment followed by an infantry attack. However, the German trenches were so well fortified that the British shells barely made an impact, so thousands of Allied troops fell victim to the ruthless German machine guns.

The end came at St Quentin Canal in France. The British managed to storm through the Hindenburg Line, forcing the Germans back and bringing about the first discussions of surrender.

Trench firepower

Trenches served as a point of attack as well as defence



Barrier
Sandbags were put here partly to act as a shield, but also to provide a stable rest for a soldier to rest his gun.

Metal roof
Some trenches would use sheets of corrugated metal as shelter for soldiers waiting in reserve.

Rifleman
Soldiers would spend up to two hours on guard duty here, keeping an eye out for an enemy offensive.

Fire step
This raised platform allowed soldiers to reach over the trench wall, which was usually slightly higher than the height of a man to avoid the enemy being able to see inside.

Job roles in the trenches

The majority of soldiers in the trenches were there to directly engage in combat. These soldiers would have a spectacular range of abilities and experiences. Some may have been grizzled war veterans, while others would be fresh recruits, straight out of training. These people would be responsible for day-to-day maintenance, guarding and, eventually, going over the top and launching an offensive on the German trenches.

Officers ① would also be stationed in the trench. They would be soldiers of higher status and would be in charge of organising and leading night patrols, which tried to keep track of the enemy's location. They had marginally more luxury than the other soldiers, sleeping in a proper dugout in the trench and having first pick of the food.

Medics ② were stationed in three positions: the collecting zone (right by the battlefield), the evacuating zone (between the front and rear trenches) and the distributing zone (where they would treat the wounded in pop-up hospitals). If a soldier couldn't be moved, they would be treated where they lay. The Royal Army Medical Corps (RAMC) is the only part of the British army in which two members hold double Victoria Crosses.

Listeners ③ would move through tunnels closer to the enemy's front line than the trenches. The idea was to try to hear enemy plans and put a halt to the enemy planting mines close to their trench. This was a very dangerous role as tunnels could collapse at any time.

①

②

③

A day on the front line

Soldiers in the British army would spend about 15 per cent of their active service on the front line and 40 per cent in the reserve trenches.

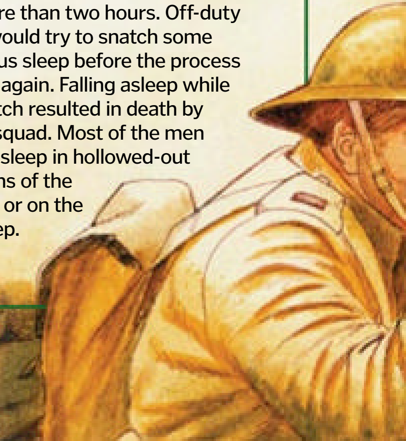
The average day on the front line would begin with a stand to. This would be around an hour before sunrise and involved all soldiers standing on the fire step, rifles ready and bayonets fixed. They would then begin the 'morning hate', firing their guns into the morning mist. This had the dual benefit of relieving tension and frustration, as well as helping to deter a possible dawn raid.

Breakfast would then be served, consisting of biscuits or bread and canned or salted meat. Following breakfast would be a period of chores. These could range from cleaning weapons and fetching rations to guard duty and trench maintenance. The latter would often involve repairing shell damage or trying to shore up the damp, underfoot conditions.

One of the main challenges in everyday trench life was the food. At the start of the war, each soldier received 283 grams (ten ounces) of meat and 227 grams (eight ounces) of vegetables per day. However, as the war wore on, the meat allowance reduced to 170 grams (six ounces) of meat and, if you weren't on the front line, you only got meat on nine out of 30 days. Diets were bulked out with corned beef, biscuits and bread made of dried ground turnips. As the kitchens were so far behind the front line, it was nearly impossible to provide hot food to the troops at the front, unless the men pooled their resources and bought a primus stove to heat their food and make tea. Other common meals included pea soup with horse meat and Maconochie, a weak soup containing sliced carrots and turnips.

As dusk fell, the soldiers would engage in an evening version of the morning hate. Essential tasks like repairing barbed wire and rotation of troops were done after dark, as the enemy was less likely to be able to launch an effective attack.

Guards would look out for night-time raids, with watches lasting no more than two hours. Off-duty men would try to snatch some precious sleep before the process began again. Falling asleep while on watch resulted in death by firing squad. Most of the men would sleep in hollowed-out sections of the trench or on the fire step.



5 TOP FACTS
TRENCHES TODAY

Sanctuary Wood
1 This is a museum and trench network 3.2km (2mi) east of Ypres. You can visit the woodland where soldiers once sheltered and walk in their footsteps in the trenches.

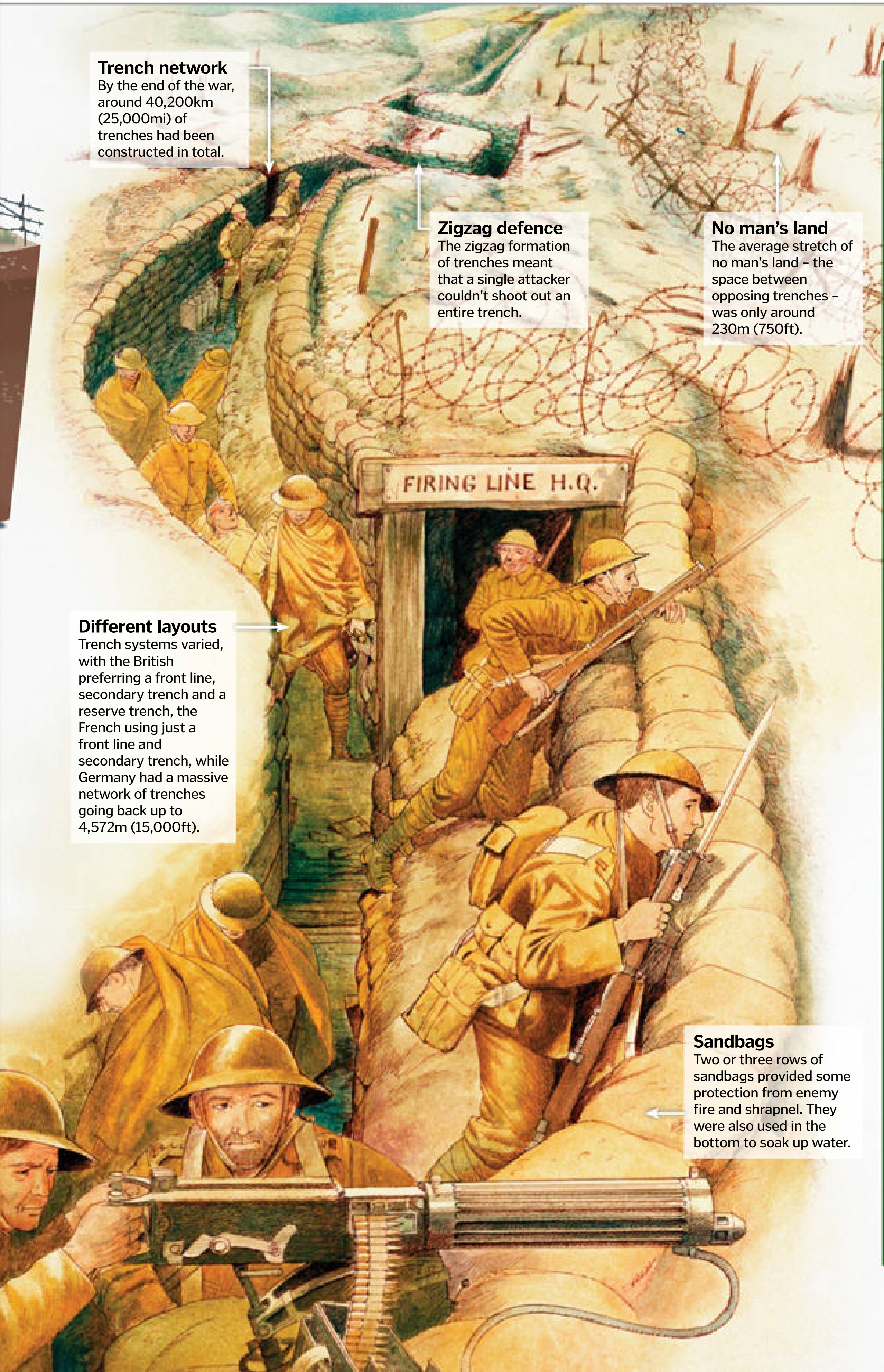
Yorkshire Trench
2 Originally dug by British troops in 1915, the Yorkshire Trench – located north of Ypres – has been restored in considerable detail and is free for all to visit today.

Vimy Memorial Park
3 Free tours to this site are provided by Canadian students. Canada was granted this piece of land after they were instrumental in taking it from Germany in 1917.

The Somme
4 One of the most significant battle sites in the war, where an estimated 60,000 men died in one day. The area is still covered in craters and trench lines to this day.

Verdun
5 Another key site in the battle for the Western Front, Verdun was the location of a bloody battle, with almost 300,000 soldiers killed over ten months of fighting.

DID YOU KNOW? *The machine gun was originally designed by American inventor Hiram Maxim as long ago as 1884*


FIRING LINE H.Q.

Trench network
By the end of the war, around 40,200km (25,000mi) of trenches had been constructed in total.

Zigzag defence
The zigzag formation of trenches meant that a single attacker couldn't shoot out an entire trench.

No man's land
The average stretch of no man's land – the space between opposing trenches – was only around 230m (750ft).

Different layouts
Trench systems varied, with the British preferring a front line, secondary trench and a reserve trench, the French using just a front line and secondary trench, while Germany had a massive network of trenches going back up to 4,572m (15,000ft).

Sandbags
Two or three rows of sandbags provided some protection from enemy fire and shrapnel. They were also used in the bottom to soak up water.

5 key WWI weapons

1 Machine gun
The machine gun was one of the definitive weapons of WWI. At the outbreak of war, Germany had 12,000 machine guns, while the British and French only had a few hundred between them.

2 Tank

Early tanks were based on farming vehicles, the caterpillar tracks allowing for movement over uneven muddy ground. They were slow and unreliable but once these problems were ironed out and they were weaponised, the British enthusiasm for the tank helped them win the war.

3 Rifle
Despite the advance of long-range or automatic weapons like machine guns and mortar shells, the rifle continued to be an essential piece of military kit.

4 Bayonet

These blades affixed to the front of rifles were only useful in close combat. The French army used needle blades, while the German army developed the saw-back bayonet blade.

5 Flame-thrower

By 1915, German soldiers had portable flame-throwers that terrified the British army at Flanders. The British attempted to come up with flame-throwers of their own, but with little success, while the French developed their own self-igniting, lightweight flame-throwers, with more success than the British.

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Flying a WWII plane

We get into the aircraft that trained pilots for World War II

It's the summer of 1940 and the German Luftwaffe is preparing to launch a mass air attack on Southern England. If they are victorious, Britain will be open to a land invasion and Blitzkrieg will be upon the British Isles. Luckily, brave and skilled RAF pilots take down the Messerschmitts in their Spitfires and Hurricanes, so the German Operation Sea Lion never materialises. But how were our pilots so skilled at air-to-air combat? A visit to Goodwood Flying School in West Sussex for a lesson way up in the sky almost exactly 74 years after the battle will most certainly help us to understand.

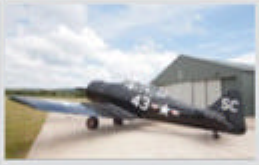
On a glorious day on the south coast, we will be over 1,200 metres (4,000 feet) in the air learning to fly like it's 1940. The plane taking flight today is not a Spitfire or a Hurricane; in fact it's not even a fighter at all. Instead it's the official World War II training plane for the RAF, the Harvard T-6, a Canadian-built Noorduyn model. Before we go skyward, we meet pilot Matt Hill who shows us the aviation ropes.

"The Harvard was used for advanced training, gunnery practice and blind flying, it had less speed and power than the Spitfire and the Hurricane as it was a trainer, not a fighter", Matt says. He then delivers a crash course on how to fly a plane so that when get on board, we won't be just a passenger – when we're in the air, we will actually have control of the plane.

Before we take to the skies it is important to know the history behind the aircraft. The Harvard was the second step in a RAF fighter pilot's training. Prior to this, a budding pilot would take to the skies in a Tiger Moth biplane. This aircraft would be used for a four-and-a-half-hour training session to hone the skills and art of flying before ramping up the power in the Harvard. Matt explains: "This plane (the Harvard) has a hydraulic system, brakes, a tail wheel and flaps, which the Tiger Moth doesn't. People who have flown the Mustang (US WWII fighter plane) say it is very, very similar."

RCAF 422
RCA

The statistics...



Harvard T-6/North American T-6 Texan

Length: 8.5m (28ft)
Wingspan: 12.8m (42ft)
Seating: Tandem
Power: 450kW (600hp)
Engine: Pratt & Whitney R-1340 Wasp
Propeller: Hamilton Standard Two-Blade 12D40 Propeller
Top speed: 338km/h (210mph)

A fleet of T-6s in 1941 ready for training drills at Randolph Field, Texas

DID YOU KNOW? *Despite the Spitfire's popularity, the Hawker Hurricane shot down more German fighters in the Battle of Britain*

RAF fighter aces during the Battle of Britain

NAME	AIRCRAFT	KILLS
Pilot Officer Eric Lock	Spitfire	21
Flight Lieutenant Archie McKellar	Hurricane	19
Sergeant James Lacey	Hurricane	18
Sergeant Josef František	Hurricane	17
Flying Officer Witold Urbanowicz	Spitfire	15

A student being shown the ropes by a Goodwood Flying School pilot

The student all dressed up and ready to go

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3830
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The Harvard was used by 30 countries as part of their respective air forces and the last military usage was as recent as 1995 in the South African armed forces.

On inspection of the Harvard, it is obvious this striking machine is almost entirely unchanged since the 1940s. In fact, a fresh coat of paint is literally the only difference. The first production model flew in 1938 and its successful test flight convinced the British to order over 300 for training purposes. Far from a relic, the original instruments are all still in complete working condition and the dual cockpits are exactly how they would have been in the war. With that, Matt calls an end to the chitchat as the runway beckons. The *Top Gun*-esque suit is donned and into the skies we go.

The flight itself lasted 40 minutes. First, we undertook a circuit of the airfield and witnessed some breathtaking views of the nearby towns of Chichester and Bognor Regis. There wasn't much time to take in the sights, however, as it was now our turn to take the reins. Matt prepared the plane for a change in control by maintaining a steady speed and making the plane level. With a slight shunting motion, the craft was now in our hands. The Harvard is controlled by a central stick which you move in the direction you want the plane to go. The stick was incredibly sensitive and a slight movement to either side would alter the plane's flight path considerably. It felt very tense being in a tiny vehicle in a huge expanse of sky.

After the short solo journey, it was time to relinquish control and hand over to Matt, who would now do some extreme aerobatic manoeuvres. We began with a full loop, which gave the experience of around 3g's worth of force. Next up was the barrel roll, which was followed by twists and dives that resulted in a similar amount of g-force. The only way to describe the feeling is to imagine the biggest and fastest roller coaster you've been on and then multiply it by ten.

Leaving Goodwood, you couldn't help but wonder how the RAF performed these amazing moves, all while engaging in warfare with the mighty Luftwaffe. It boggles the mind that these brave men did this just a touch over 70 years ago. The Harvard T-6 is a wonderful machine and undoubtedly a key component in the RAF having the skill to win the Battle of Britain and halt the German advance.

To try your hand at flying a World War II plane for yourself, visit **www.goodwood.co.uk/aviation** for more information.

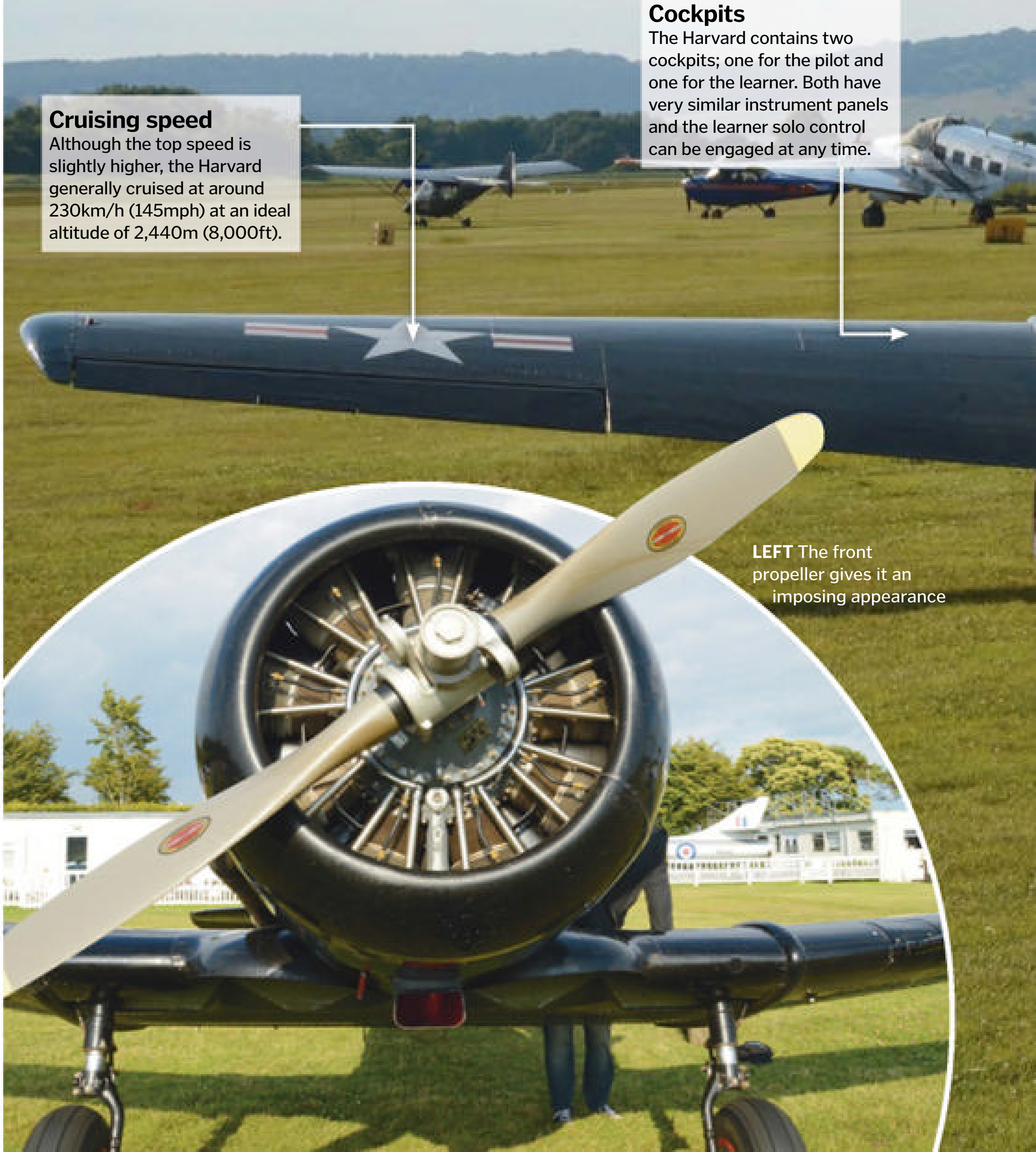
The Harvard's modern cousin

On the day, we also had the chance to test out another plane, the Cessna 172S Skyhawk, which is one of the planes used currently to train new pilots. However, the one most like the Harvard is the Swiss-built Pilatus PC-21. Used to train modern-day fighter pilots, the PC-21 provides an ideal introduction to flying jet-based fighters. It can be used for both beginner and advanced training, using a turboprop engine that uses a propeller flown by a turbine. It can reach speeds of up to 685 kilometres (425 miles) per hour and current customers include the air forces of Singapore, United Arab Emirates and the Royal Saudi Air Force.

The Cessna 172S Skyhawk, a new training plane

The Harvard: inside and out

A trip around the T-6 and its main features



Cockpits
The Harvard contains two cockpits; one for the pilot and one for the learner. Both have very similar instrument panels and the learner solo control can be engaged at any time.

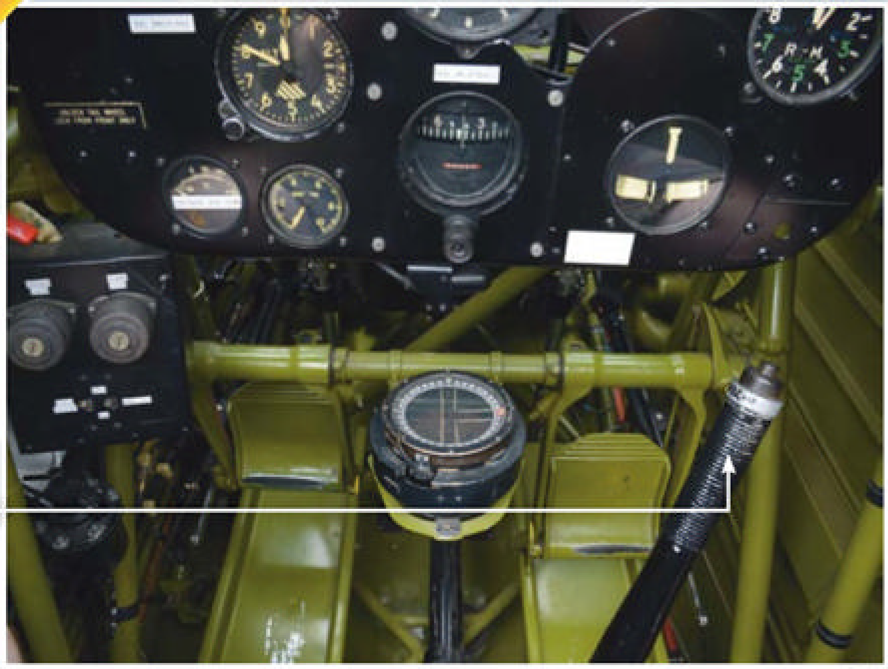
Cruising speed
Although the top speed is slightly higher, the Harvard generally cruised at around 230km/h (145mph) at an ideal altitude of 2,440m (8,000ft).

LEFT The front propeller gives it an imposing appearance

THE STATS
BATTLE OF BRITAIN

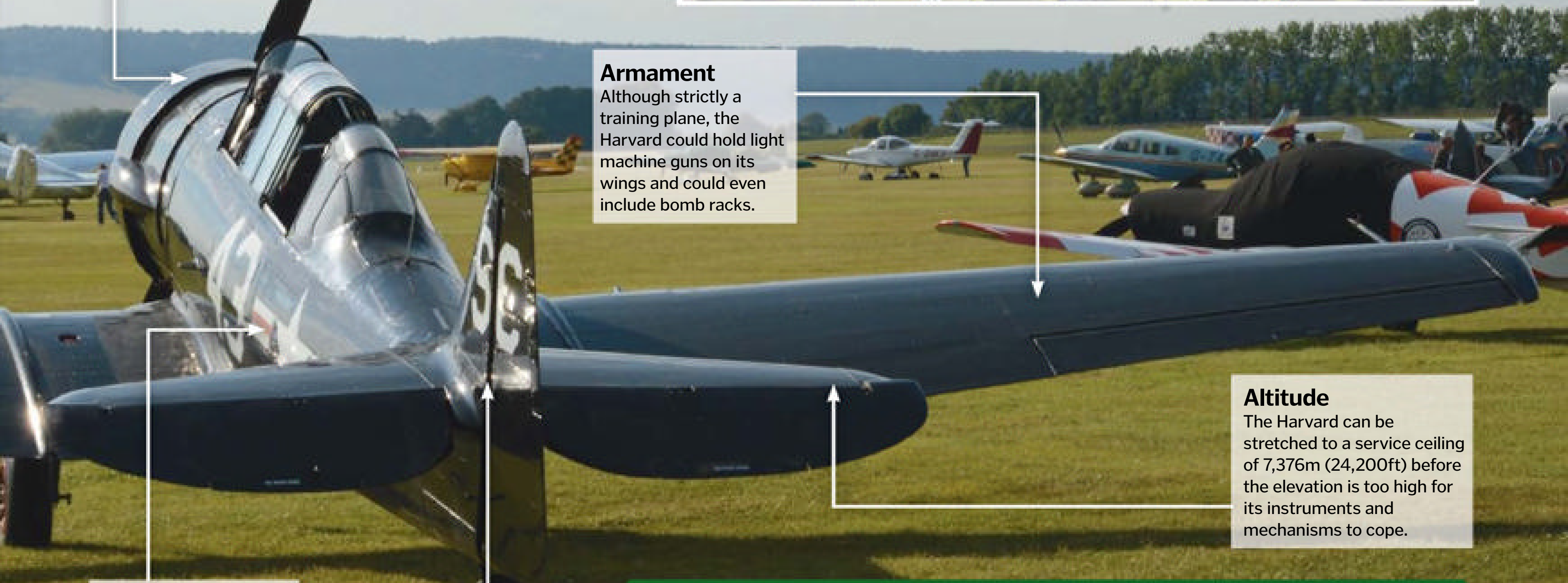
1,012 RAF LOSSES
1,918 LUFTWAFFE LOSSES
2,927 ALLIED PILOTS
601 HURRICANES SHOT DOWN
357 SPITFIRES SHOT DOWN

DID YOU KNOW? *The Harvard is used to portray Japanese Mitsubishi Zeros in several war films, such as 1987's Empire of the Sun*



In action
In the war the T-6 could also function as a FAC (forward air controller) to support frontline troops by surveying the local area.

Control
Steering is done using the centre stick, although differential braking in the tailwheel can be used as well.



Armament
Although strictly a training plane, the Harvard could hold light machine guns on its wings and could even include bomb racks.

Altitude
The Harvard can be stretched to a service ceiling of 7,376m (24,200ft) before the elevation is too high for its instruments and mechanisms to cope.

Range
On a full tank and in good conditions, the plane can fly up to 1,175km (730mi). That's further than from John o' Groats to Land's End!

Hydraulic system
Activated by a push of a button, the system allows you to use the gears and flaps on the plane.

On the Tiger Moth biplane

A trip on a Tiger Moth is very different to a Harvard flight. As it's a biplane, flights are completed at a much lower altitude and at considerably slower speeds. This is ideal for the beginner pilot to understand the controls before ramping the difficulty up to the Harvard. The controls in the biplane are less responsive than most, so piloting it is actually pretty tricky. The RAF liked this quality as it quickly separated the talented pilots from the rest. The 'Moth' is a semi-aerobatic plane, so it can still loop and barrel roll, which made it an ideal starter plane for RAF training.

The Tiger Moth served as a preliminary training plane

© Eric Dumigan www.airic.ca/Harvards; Corbis

The Sherman Tank

How this famous tank led the Allied war machines in WWII

The first use of the tank as a military weapon was in the First World War at the Battle of the Somme. Armoured vehicles would become a big part of warfare but it wasn't until the Second World War that they became essential. The most essential of all the Allied tanks was the Sherman.

Titled the M4 Medium Tank, it was named after William Tecumseh Sherman, who was a Union general in the American Civil War. It replaced the M3 armoured vehicle and was provided as part of the American Lend-Lease policy to its allies. It was first used in 1942 by the British, to tussle with the German Panzer IIIs and IVs for battlefield supremacy.

The Sherman was based on speed and manoeuvrability. It had weaker armour and less equipment than its German counterparts and with the introduction of the Axis' Tiger and Panther models, it became inferior on the battlefield. This was soon remedied with the introduction of the Firefly, Jumbo and Easy Eight variants. The tank's main tactic was to fire an armour-piercing round and then incinerate the unarmoured and exposed enemy tank. Shermans were always fielded in great numbers and worked well in partnership with M10 Tank Destroyers. The Sherman was used extensively in the African, French and Italian campaigns until the end of the war. Some models could attach a flamethrower, rocket launcher or bulldozer blade, as well as amphibious versions, which were used in the D-Day landings.

Even after the war, the Sherman was still used frequently. Its reliability and low running cost allowed it to be deployed in the Korean War, as well as by other nations, with Australia, Brazil and Egypt and many more having their own variations of the successful Sherman model.

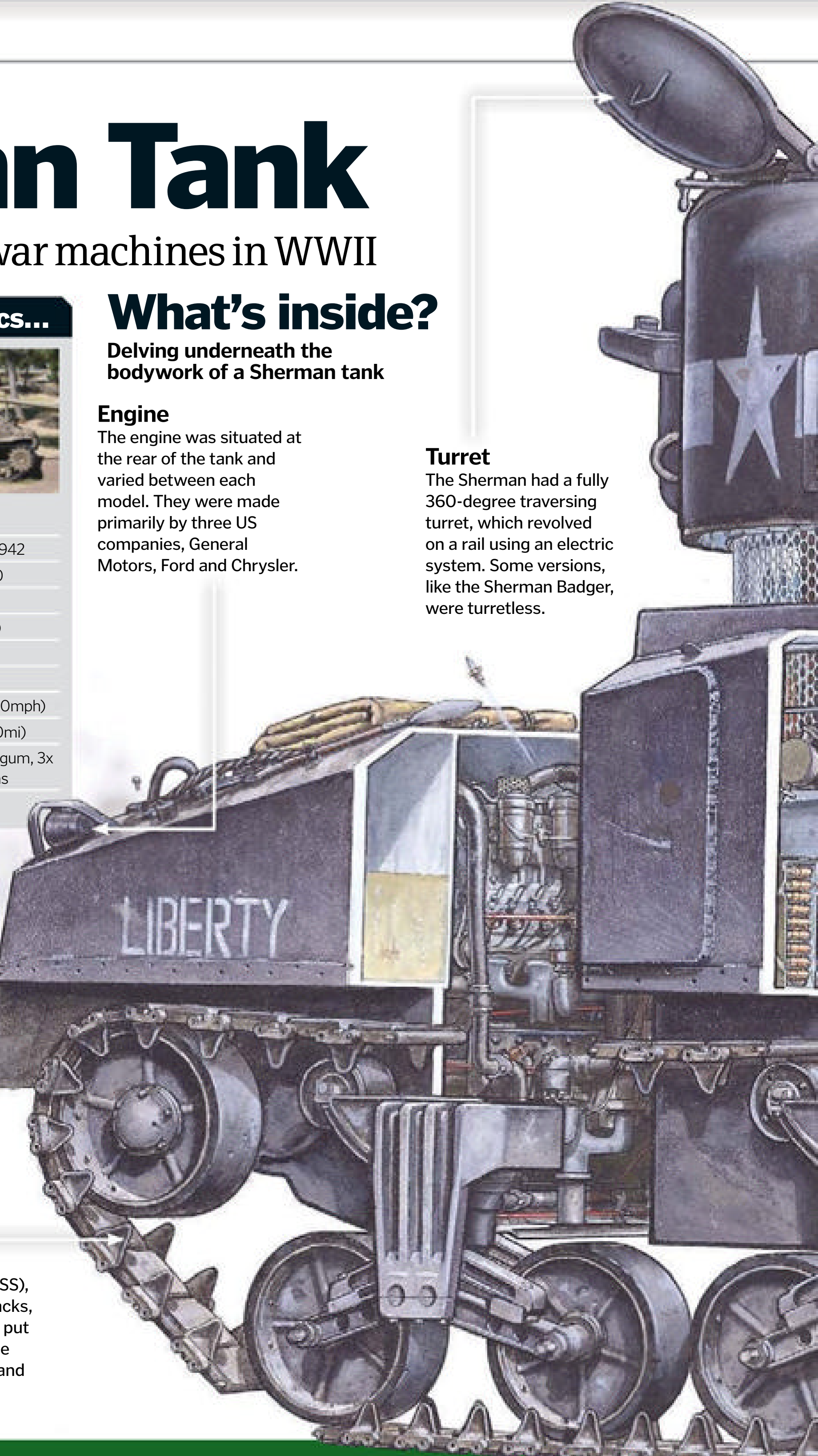
The statistics...

M4 Sherman

First year of service: 1942
Amount made: 50,000
Crew: Five
Length: 5.84m (19.16ft)
Width: 2.62m (8.6ft)
Height: 2.74m (8.99ft)
Max speed: 48km/h (30mph)
Max range: 193km (120mi)
Weapons: 75mm main gum, 3x machine guns
Engine: 317kW (425hp)

What's inside?

Delving underneath the bodywork of a Sherman tank



Engine
The engine was situated at the rear of the tank and varied between each model. They were made primarily by three US companies, General Motors, Ford and Chrysler.

Turret
The Sherman had a fully 360-degree traversing turret, which revolved on a rail using an electric system. Some versions, like the Sherman Badger, were turretless.

Tracks
Using a Vertical Volute Spring Suspension (VVSS), the tank had 78-link tracks, which was designed to put minimal pressure on the ground to keep it light and nimble on all terrain.

The various members of the Sherman tank family

1 M4A3E2 Jumbo
Designed for the liberation of Europe, the Jumbo weighed 38 tons, it was very well protected, resisting all German anti-tank guns.

2 M4A3E8 Easy Eight
Smaller and more mobile yet with the same armour as the Jumbo, this variant saw frequent postwar service, such as in Korea and Vietnam.

3 M4A3R3 Zippo
Known as a 'flamethrower tank', designed to flush out pillboxes and bunkers. It was mainly used in the Far East theatre of war.

4 T34 Calliope
Carrying a rocket launcher, this tank only came into use at the tail end of WWII but was highly effective against fortified defences.

© DK

HEAD 2 HEAD

TOP WWII TANKS

1. TOUGH

T-34

The T-34 was a heavily armoured Soviet battle tank with good firepower. The trusty and durable T-34 is still used by some countries today.

2. TOUGHER

Panther

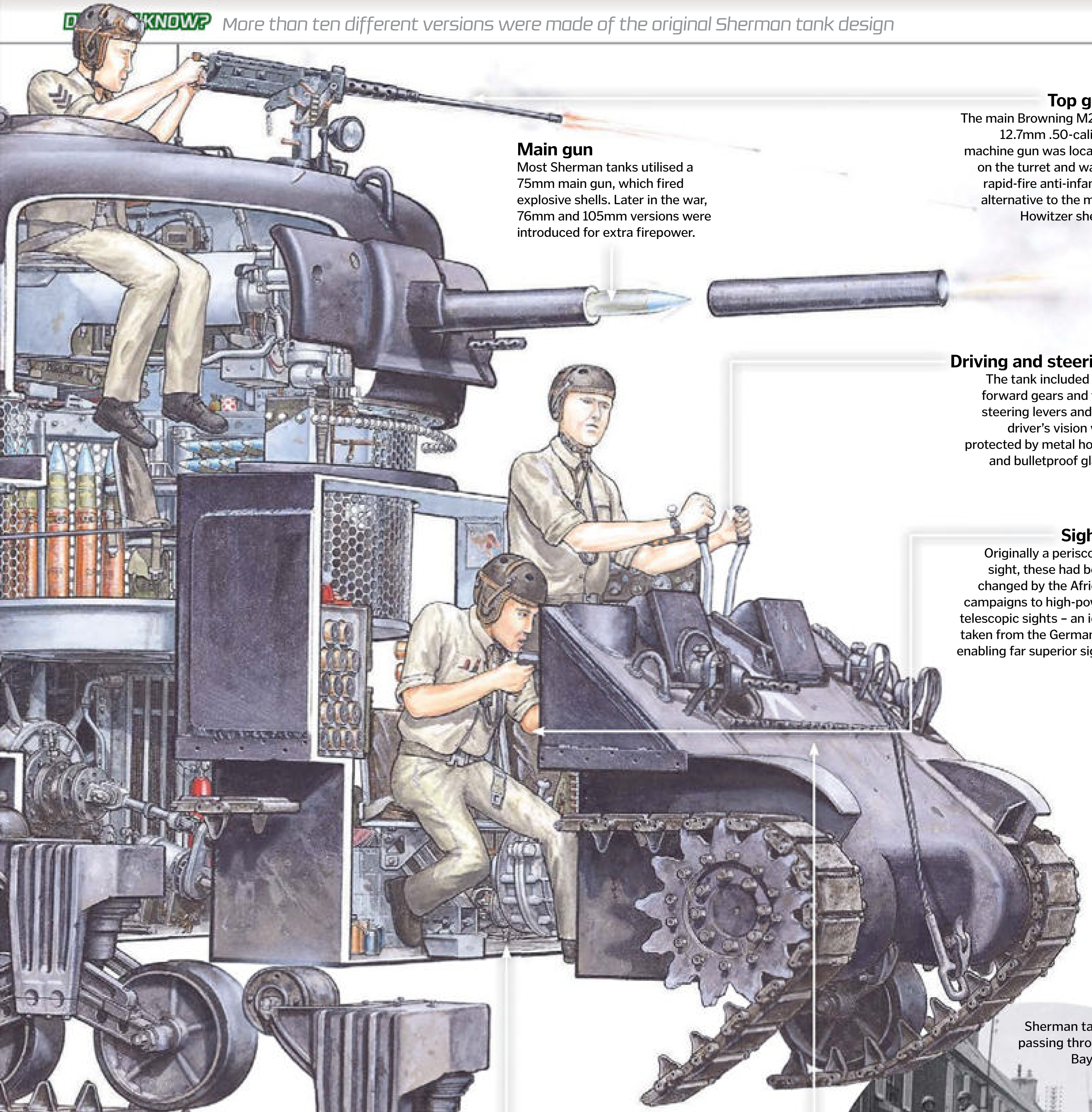
This German tank's protection was so tough that it was still used as standard by several other nations around the world after the war.

3. TOUGHEST

Firefly

Designed by the British, it was the only Allied tank that could take on the fearsome German Panthers and Tigers and have a hope of winning.

D[illegible] KNOW? *More than ten different versions were made of the original Sherman tank design*



Main gun

Most Sherman tanks utilised a 75mm main gun, which fired explosive shells. Later in the war, 76mm and 105mm versions were introduced for extra firepower.

Top gun

The main Browning M2HB 12.7mm .50-calibre machine gun was located on the turret and was a rapid-fire anti-infantry alternative to the main Howitzer shells.

Driving and steering

The tank included five forward gears and two steering levers and the driver's vision was protected by metal hoods and bulletproof glass.

Sights

Originally a periscopic sight, these had been changed by the African campaigns to high-power telescopic sights – an idea taken from the Germans – enabling far superior sight.

Escape hatch

To allow for quick escapes after sustaining damage, later models included an emergency hatch on the floor below the bow gunner.

Machine gun

The bow gunner had a 7.62mm .30-calibre machine gun to strike closer and faster infantry. It was protected by a reinforced sloped front hull.

Sherman tanks passing through Bayeux

Brutal battering rams

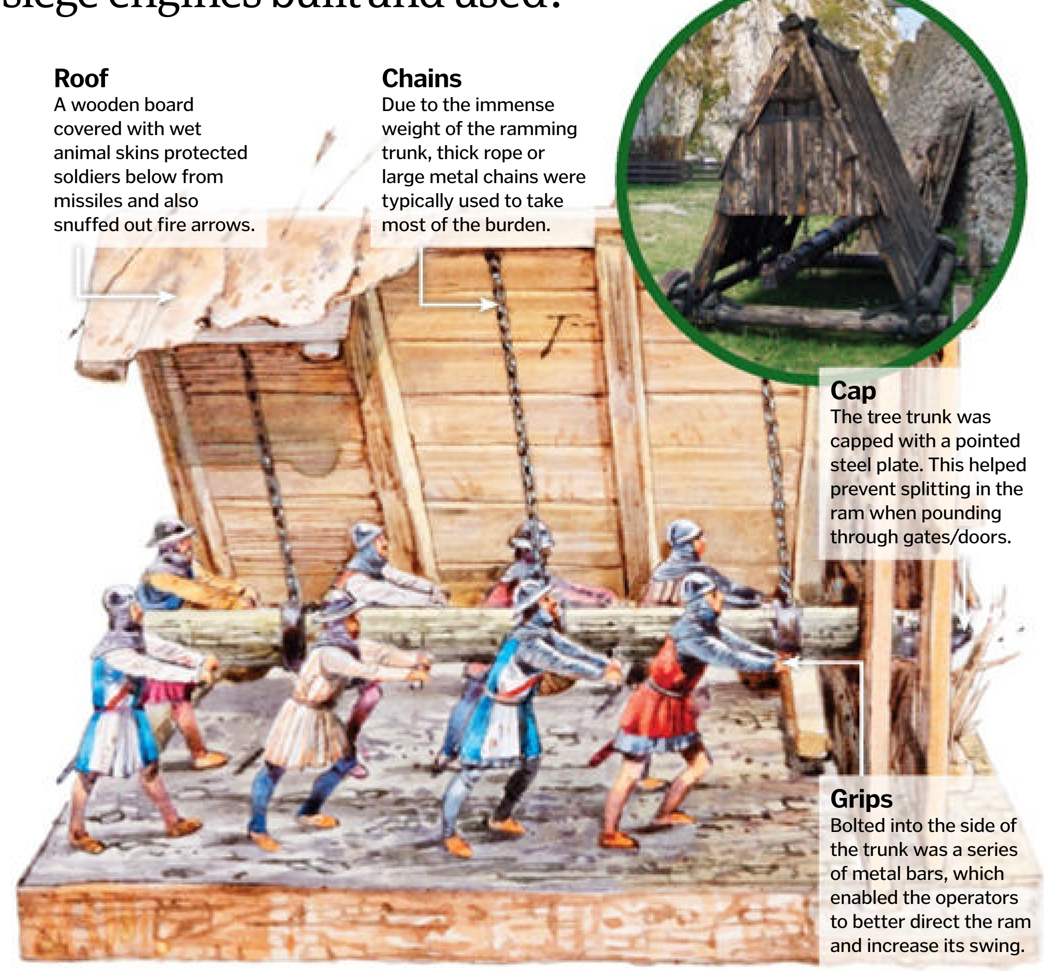
How were these powerful siege engines built and used?

Battering rams were one of the most common pieces of siege equipment from antiquity right through to the Middle Ages, often granting offensive forces access to an enemy's fortified stronghold or city.

A typical battering ram consisted of a rectangular wheeled frame from which a large tree trunk was slung via ropes or chains. The suspended trunk would then be rocked backwards and forwards within the frame until it swung with great force. By placing an obstacle – such as a wooden gate – in the ram's path, it could transfer a vast amount of energy into the target, often shattering the defence.

However, for a ram to get up to speed, a team of soldiers was required to first place it in position and also control its swinging – both of which are difficult when under fire by ranged weapons. To counter this, battering rams often featured triangular wooden coverings stretched with wet animal hides. This shielding not only protected the soldiers from direct missile strikes but also the risk of fire, with the hides extinguishing any flaming arrows.

The age of the battering ram came to a close largely due to the proliferation of gunpowder and explosives in the late-Middle Ages, with army sappers using these incendiary devices to bring down gates and walls much faster.



Roof
A wooden board covered with wet animal skins protected soldiers below from missiles and also snuffed out fire arrows.

Chains
Due to the immense weight of the ramming trunk, thick rope or large metal chains were typically used to take most of the burden.

Cap
The tree trunk was capped with a pointed steel plate. This helped prevent splitting in the ram when pounding through gates/doors.

Grips
Bolted into the side of the trunk was a series of metal bars, which enabled the operators to better direct the ram and increase its swing.

What other weapons were used in siege warfare?

Trebuchet
One of the most useful siege weapons ever to be created, the catapult-style trebuchet allowed an army to bombard a city's walls and interior buildings with huge stones, flaming balls of earth and even dead animals (the latter spreading disease and panic throughout the inhabitants). On the downside, trebuchets required a large team to operate effectively.

Ballista
A large missile-throwing weapon, the ballista was an excellent choice when you wanted to disrupt infantry columns. Developed first by the Ancient Greeks, the ballista worked via torsion springs, with huge wooden spikes propelled at great speed when released over large distances. The ballista would be scaled down over the centuries until eventually it could be handheld.

Tower
A simple yet devastatingly effective siege weapon if used correctly, the tower was literally a mobile wooden turret on wheels that enabled troops to scale enemy walls in relative safety. After climbing up through the shielded internal cavity, soldiers would then be released with the dropping of a small drawbridge, enabling them to charge over enemy battlements.

© Thinkstock

5 TOP FACTS
ZULU WEAPONS

Axe
1 A semi-circular iron blade attached to a wooden handle, the Zulu axe was used by the most esteemed leaders and had to be held in both hands.

Club
2 A 0.6m (2ft) hardwood club with a knob on the end, the iwisa – also known as the knobkierie – can either be thrown or used similarly to a mace.

Spear
3 A long, thin throwing javelin, the ipapa spear was once the traditional weapon of the Zulu, but it was replaced with the shorter iklwa by Shaka.

Poison
4 Zulu warrior would poison their spear-tips with an extract from the bark of the combretum caffrum tree. Parts of the tree are also used in traditional medicine.

Rifle
5 The Zulus also captured many single-shot Martini-Henry rifles at the start of the Anglo-Zulu War. These were the standard firearm of the British Army.

Secrets of the Zulu warriors

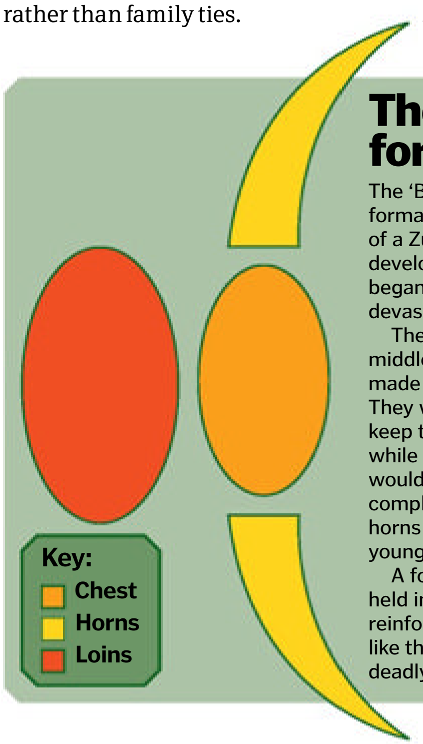
How did the Zulus become South Africa's most feared fighting force?

From 1816 to 1879 the Zulu Kingdom became one of the most powerful tribal societies in what is now South Africa. Only the arrival of the British Empire finally ended their expansion across the KwaZulu-Natal region in the bloody Anglo-Zulu War of 1879, after which the Zulu Kingdom became subject to the authority of Queen Victoria.

Born around 1787, Shaka Zulu, the illegitimate son of chieftain Senzangakhona, had a lot to prove, and he did so the hard way. Taking control after his father's death, Shaka curbed the power of the witch doctors and transformed the army with reforms. Among those was a policy of absorbing defeated tribes into his kingdom and promoting men based on ability rather than family ties.

Zulu warriors also gained new weapons, including the short, stabbing iklwa spear (the name gruesomely said to be the sound made when pulled from a corpse), and revised tactics. Zulu warriors were trained harshly too, forced to throw away their sandals so they could run faster – those who complained were simply killed – they reportedly jogged up to 80 kilometres (50 miles) in a day, with children as young as six running after them with food and other supplies.

By Shaka's death in 1828, the Zulu Kingdom had expanded to cover an incredible 29,800 square kilometres (11,500 square miles) and ruled an estimated 250,000 people.



Key:
🟧 Chest
🟨 Horns
🟥 Loins

The Zulu's killer formation

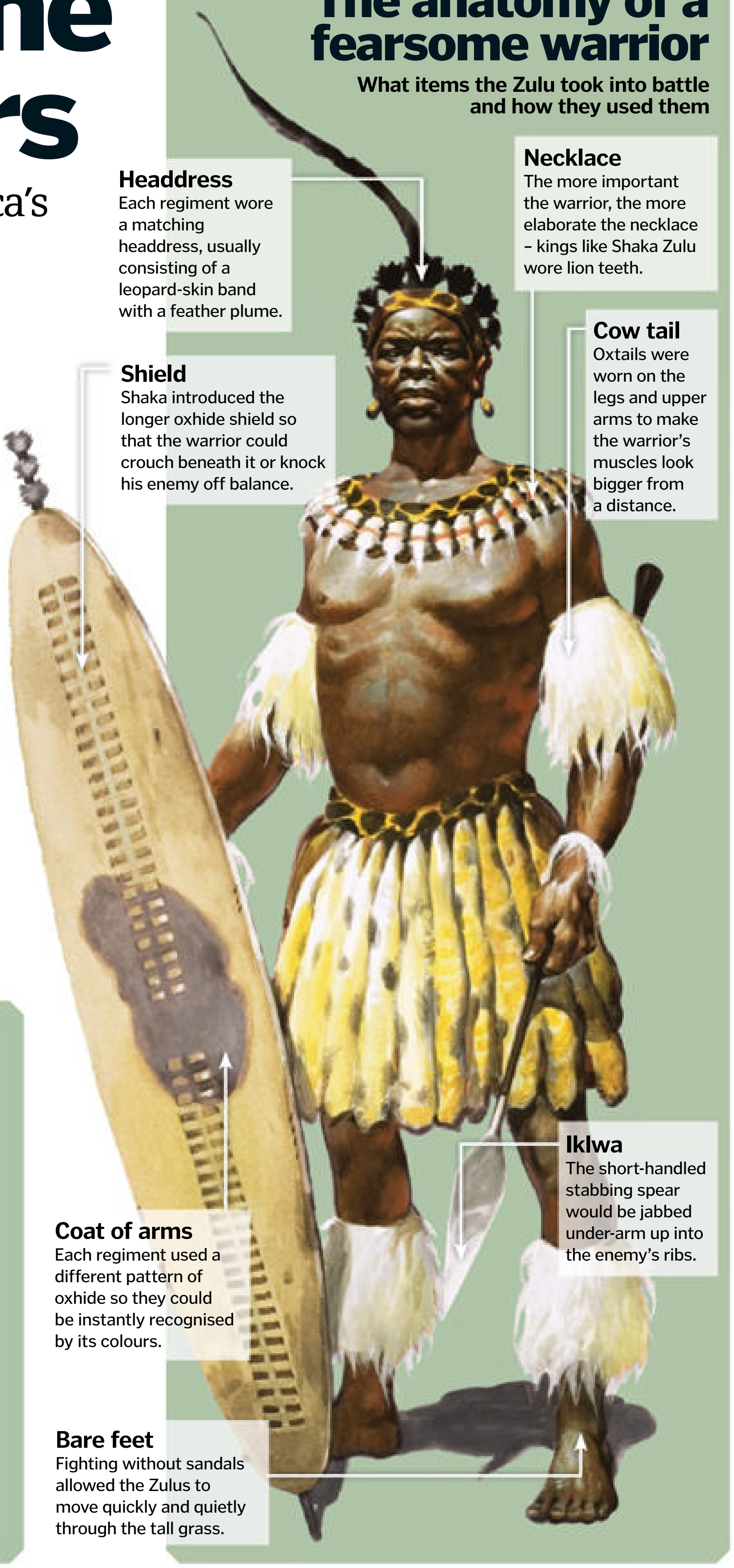
The 'Buffalo horn' or 'bull-horn' formation was the core battle strategy of a Zulu army. It had originally been developed for hunting, but Shaka began to use it in battle, with devastating success.

The bulk of the force would be in the middle as the 'chest' of the buffalo, made up of battle-hardened warriors. They would charge into the enemy and keep them well and truly occupied while two smaller forces of 'horns' would circle around either side to completely surround their foe. The horns were often comprised of younger and faster warriors.

A fourth force, the 'loins', would be held in reserve ready to provide reinforcements if the enemy looked like they might break out of the Zulu's deadly trap.

The anatomy of a fearsome warrior

What items the Zulu took into battle and how they used them



Headdress
Each regiment wore a matching headdress, usually consisting of a leopard-skin band with a feather plume.

Necklace
The more important the warrior, the more elaborate the necklace – kings like Shaka Zulu wore lion teeth.

Cow tail
Oxtails were worn on the legs and upper arms to make the warrior's muscles look bigger from a distance.

Shield
Shaka introduced the longer oxhide shield so that the warrior could crouch beneath it or knock his enemy off balance.

Iklwa
The short-handled stabbing spear would be jabbed under-arm up into the enemy's ribs.

Coat of arms
Each regiment used a different pattern of oxhide so they could be instantly recognised by its colours.

Bare feet
Fighting without sandals allowed the Zulus to move quickly and quietly through the tall grass.

© Getty

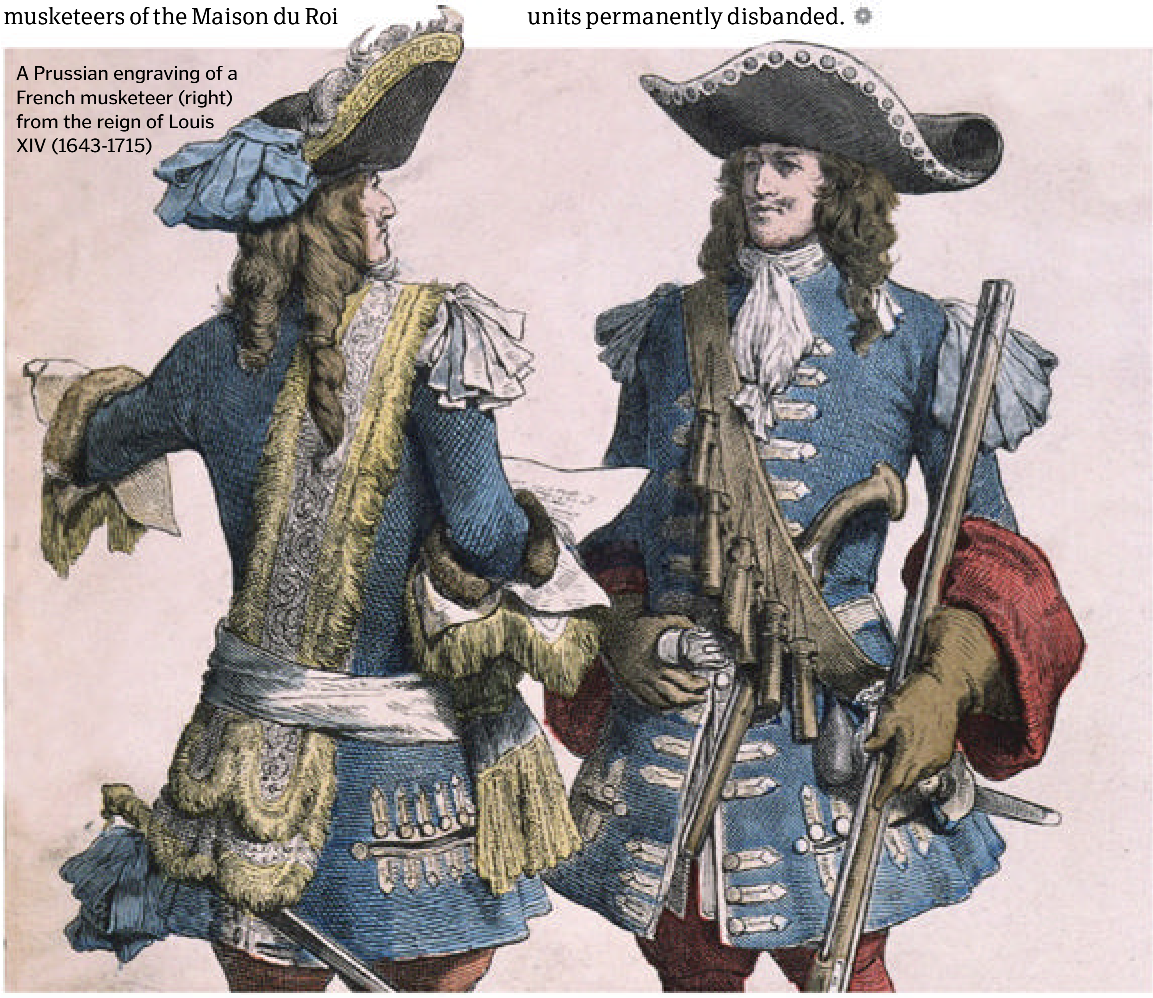
Meet the musketeers

One of the most popular military units for centuries, musketeers fought in battles and protected esteemed rulers all the way from France to India

Musketeers were an early form of soldier who were armed with muskets. They acted as a bridge unit between traditional infantry – which fought on foot and typically hand-to-hand with swords – and dragoons, a type of light cavalry armed with long-ranged weapons. This granted them a level of versatility and flexibility most prized on the battlefield, with musketeer units typically reserved for the protection of nobility or, in many Western nations, royalty.

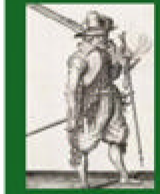
While musketeers as a unit are older (see 'Musketeer origins' boxout for details), they didn't emerge in Europe until the 16th century, with the concept only really taking off on a large scale in the early-17th century. While this particular era was dominated by the French musketeers of the Maison du Roi (the Royal Household) – upon which the fictional musketeers of Dumas's *The Three Musketeers* are based – Spain, Britain, Russia, Sweden, Poland and even India each developed their own musketeer units in this period and used them on the battlefield frequently.

Musketeers as a common military unit were largely phased out by the middle of the 19th century, with developments in firearms rendering the musket obsolete. With the introduction of the rifle – which could shoot both farther and much faster than the musket – the rifleman unit could emerge, negating the need for the greater speed of the mounted musketeer. This, combined with the decline of many dynasties throughout Europe – like the Ancien Régime of France – saw all musketeer units permanently disbanded.

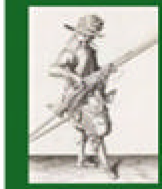


A Prussian engraving of a French musketeer (right) from the reign of Louis XIV (1643-1715)

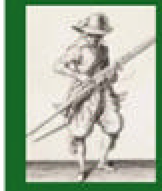
How to fire a musket step-by-step



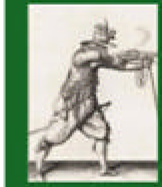
1 Carry While marching to position the musket should be carried over the shoulder, with the firing rest secured in your off-hand.



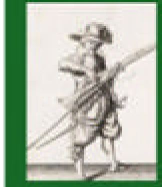
2 Firing prep When firing is ordered, the musket is filled with priming powder, charge and ball, with the weapon held in a diagonal orientation.



3 Insert fuse The match fuse should then be cocked in the matchlock and blown on, ensuring at all times that the match doesn't extinguish.



4 Shoot Draw up the musket while simultaneously securing the firing rest. Slot the musket in the rest's support brace, aim and fire.



5 Withdraw Bring the musket off its rest, draw it down to your side, then take the fuse off the musket and await further instructions.

5 TOP FACTS
MUSKETEER MYTHS

Comte d'Artagnan

1 The real Comte d'Artagnan was nothing like the fictional hero portrayed in Alexandre Dumas's famous novel *The Three Musketeers*, which itself was based on a semi-fiction.

For richer, not poorer

2 In fact, far from emerging from poor and humble origins, the real-life D'Artagnan was the son of a nobleman who lived in a large chateau in south-west France.

More than three

3 Despite the Dumas novel being called *The 'Three' Musketeers*, halfway through D'Artagnan officially joins their ranks, taking the number of musketeers in the tale to four.

Behind the times

4 Despite Dumas's novel stating that D'Artagnan left his home to become a musketeer in 1625, in fact the real man did not do so until later – during the 1630s.

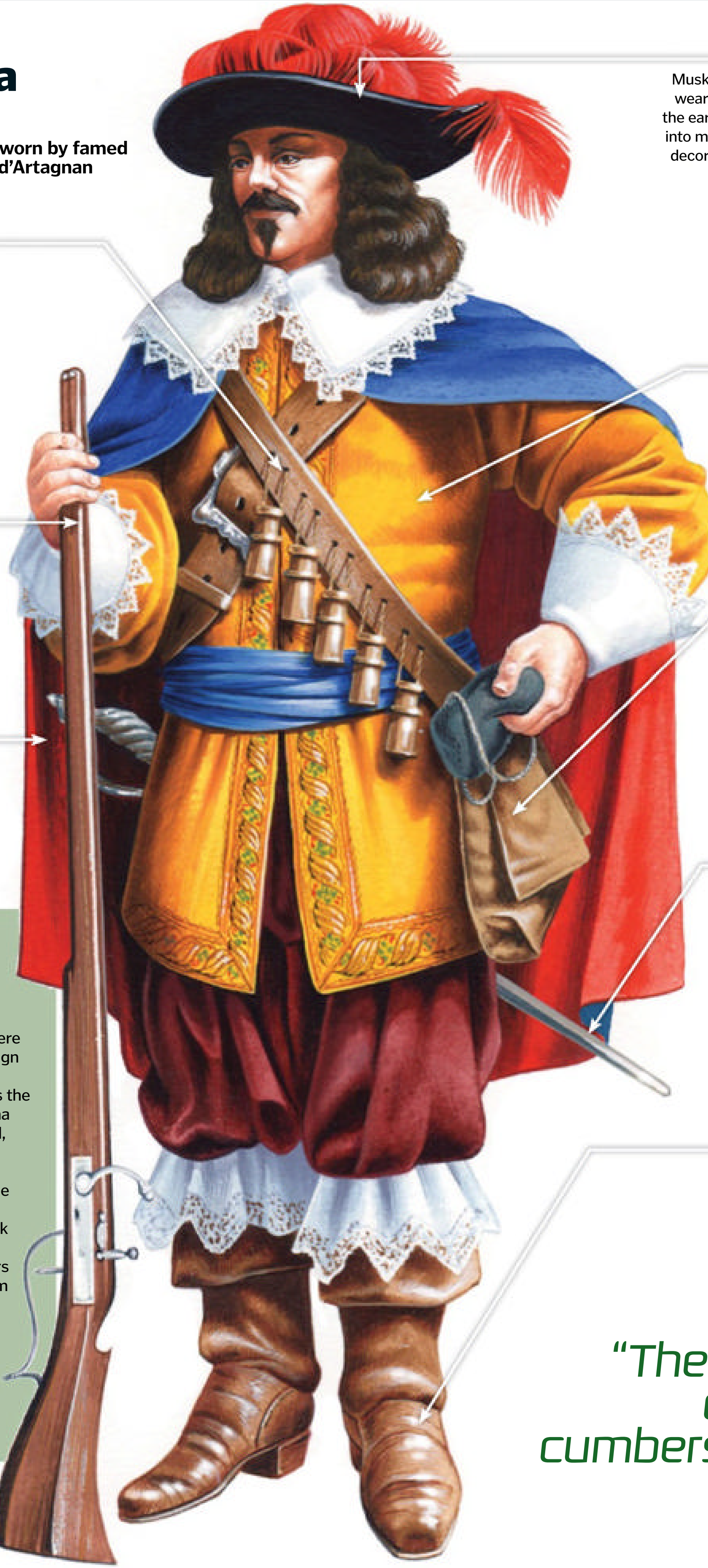
Mort realistic

5 Indeed one of the only things in Dumas's fictionalised account of D'Artagnan that is 100 per cent accurate is the date of the soldier's death – he died in Maastricht in 1673.

DID YOU KNOW? Musketeers of the Guard fought both on foot and on horseback

Uniform of a musketeer

Check out the essential kit worn by famed musketeer captain, Comte d'Artagnan



Hat
Musketeers started off in the West wearing simply ornate hats, but by the early-19th century these evolved into metal helmets. They did remain decorative though, often with large feathered plumes attached.

Bandolier
Bandoliers (a pocketed belt) and ammunition pouches/bags were a common accessory for musketeers, so they were always well supplied on the battlefield. These belts were strapped around the waist or chest.

Tunic
Considerably more elaborate than standard infantry, musketeer tunics and – in later periods – cuirasses, favoured manoeuvrability over armoured protection.

Musket
The musketeer's primary weapon, the musket was deadly albeit cumbersome to use. Its slow reload rate restricted use to four shots per minute at best.

Holdall
As musketeers were on the road during much of their military service, each carried their own holdall to store food and personal belongings.

Cape
A feature associated more with earlier iterations of musketeers, the cape offered some protection from the elements while travelling.

Sword
As musketeers were trained to fight both on horseback like dragoons and on foot like infantry, they were also equipped with a sword for hand-to-hand engagements.

Boots
Boots were an important part of the musketeer's uniform, both communicating their prestigious position and providing good support on the ground and on horseback (some had spurs attached).

Musketeer origins

Unlike the musketeers of the Maison du Roi – the Royal Household of France – who were founded in 1622 during the reign of Louis XIII, musketeers had already been operating across the other side of the world in China since the 14th century. Indeed, through the Ming Dynasty (1368-1644) no national army was complete without multiple musketeer divisions, with soldiers armed with matchlock muskets. Surviving texts indicate that these musketeers fired in lines and typically from a kneeling position. This development of the concept of musketeers in China stemmed from their invention and mastery of gunpowder, with the musket revolutionising traditional forms of combat.

> "The musket was deadly, albeit cumbersome to use"

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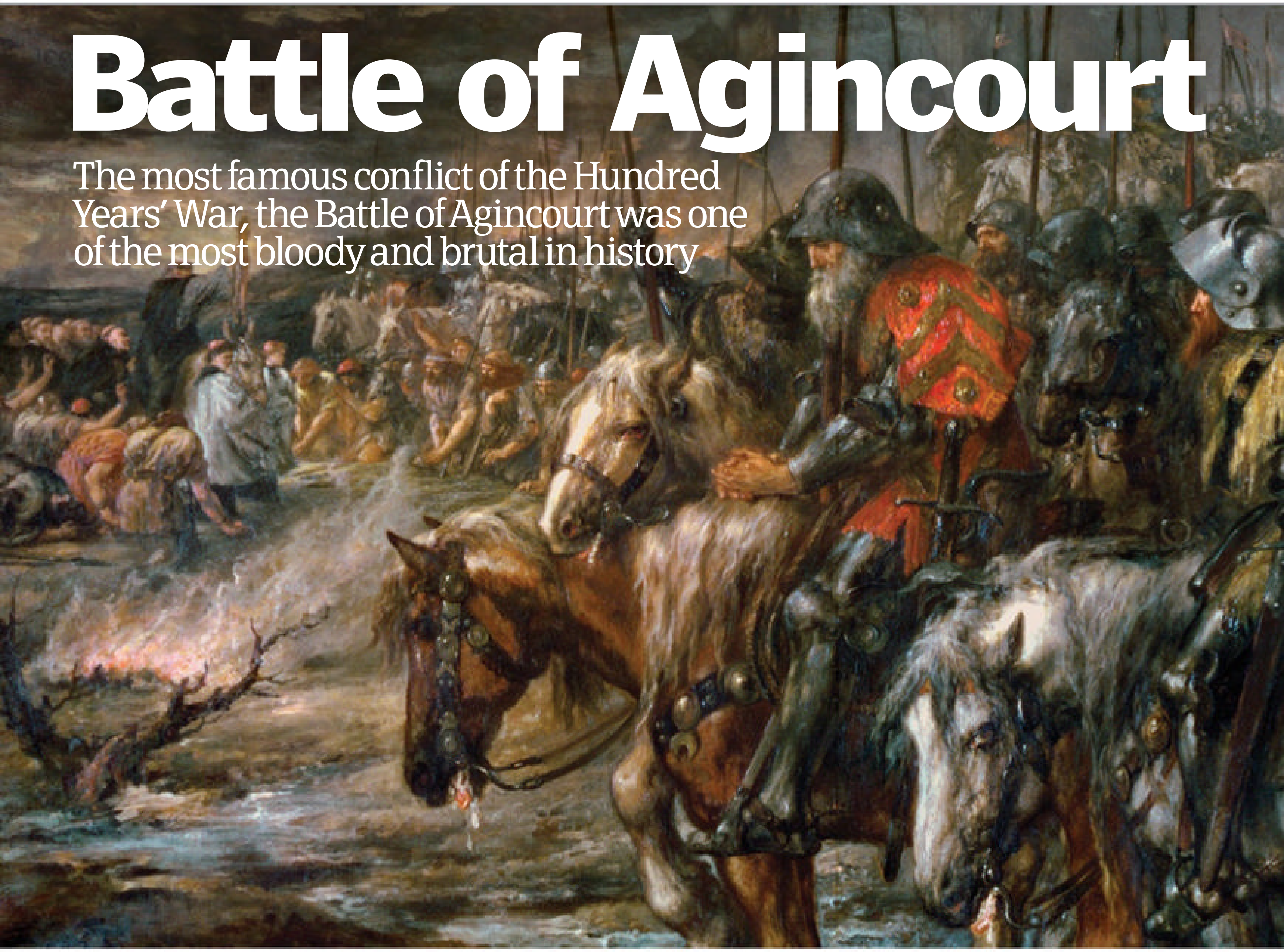


Battle of Agincourt

The most famous conflict of the Hundred Years' War, the Battle of Agincourt was one of the most bloody and brutal in history

The Battle of Agincourt is one of Europe's most famous battles, echoing down the centuries in historical record, song and even dramatic re-enactment on stage and film. The battle itself was part of the Hundred Years' War, a series of conflicts that actually waged for over a century (1337-1453) between the Kingdoms of England and France for control of the French throne.

The two contenders for the throne were the House of Valois, a noble French family from the Capetian dynasty that had claimed the throne under Salic Law, and the House of Plantagenet's Angevin family, who contested the claim due to the ancestral marriage of Edward II of England to Isabella of France. These contested claims led to a number of brutal battles throughout the 14th and 15th centuries, which came to a head in the Battle of Agincourt, a horrific battle fought between King Henry V and King Charles VI on 25 October 1415.

The battle itself was a major English victory against a numerically superior French army – see 'Agincourt battle map' for a comprehensive rundown – that rested on a series of tactical mistakes by the French, commanded by Constable Charles d'Albret, and a series of tactical masterstrokes by King Henry V. Indeed, Agincourt has gone down in French history as one of their most disastrous defeats, with around 8,000 French troops killed and hundreds of others wounded or taken prisoner. In contrast, the English losses were in the low hundreds.

Interestingly, however, despite the conflict being such an obvious and celebrated English victory, the battle is remembered today more for its vivid representation of the polarised views and consequences that war in general generates (for William Shakespeare's take on this, see 'The turning of the tide' boxout over the page). There are a number of reasons why opinions about it are so divided.

The first is due to the sheer magnitude of the casualties and the way in which they died. Records indicate men were decapitated, cleaved in two, had their bones shattered, were trampled to death, suffocated and had their major organs shredded by arrows. The battle was, without doubt, one of the bloodiest meat-grinders ever witnessed.

The second, and arguably more poignant reason, is despite Henry winning the day at Agincourt and later being named regent and heir to the French throne – a goal he had chased all his adult life – he died before he could be crowned and his successors proceeded to quickly lose both the throne and much of the territory in mainland France that he had won through his campaign.

Lastly, despite Henry's actions being accepted as justified at the time by both French and English chroniclers, his actions were heavily criticised both morally and ethically in later times. Arguments not only

5 TOP FACTS
BATTLE OF AGINCOURT

Victory songs

1 After the English victory at Agincourt, several celebratory songs were written. The most famous of these is *The Agincourt Carol.*

V

2 The derogatory 'V' sign of modern culture stems from Agincourt. The gesture was used by English archers in defiance of the French threat that any caught longbowmen would have their two bow-fingers cut off.

Outnumbered

3 One of the most contended issues today is exactly how badly the French outnumbered the English forces. Conservative figures lie around 4:3, while other estimates place it at 4:1 or even 6:1.

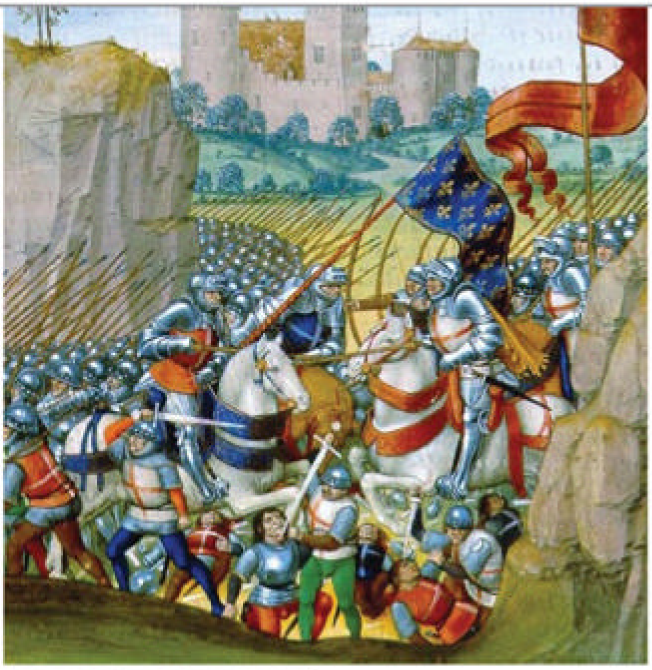
Welsh allies

4 The English forces at Agincourt were not just from England but Wales too. Indeed, one of the most notable generals, Dafydd Gam, died in the battle after reportedly saving Henry's life.

The waiting game

5 Despite Henry's resounding victory, he was not officially recognised as regent and heir to the French throne until 1420, five years after the conflict.

DID YOU KNOW? *Actor Kenneth Branagh played Henry V in the 1989 film adaptation of Shakespeare's play*



Agincourt today. Despite almost 600 years having passed since the famous battle, the terrain is still ploughed fields, a factor that greatly contributed to the English victory

© Alamy

The English frontline amasses on the morning of 25 October 1415, the day of the Battle of Agincourt

© Getty Images

contested his right to invade, but also his decision to execute all but a handful of the French prisoners taken at the battle, which while numbers are unclear, probably approached, or even exceeded, a thousand men. Indeed, the French losses at Agincourt largely obliterated their aristocracy, with hundreds of noblemen (including three dukes, eight counts and one viscount), knights and even an archbishop killed in the fighting.

In this feature **How It Works** breaks down the main events of the battle itself, analyses the surrounding context, highlights the key players and explores the ramifications that Agincourt had on the economic, social and political spheres of Europe in the Late Middle Ages and beyond.

A clash of kings

Let's pit the warring monarchs of France and England head-to-head

King Charles VI		King Henry V
46	**Age (at Agincourt)**	29
1368	**Born**	1386
House of Valois	**Lineage**	House of Lancaster
4	**Children**	1
Catholic	**Religion**	Catholic
1380-1422	**Reign**	1413-1422
Charles V	**Predecessor**	Henry IV
1422 in Paris	**Death**	1422 in Bois de Vincennes

Background: Nicknamed both Charles the Beloved and Charles the Mad, King Charles VI ruled France for 42 years despite frequently succumbing to bouts of mental illness (see 'The mad king' boxout on page 79). He was the son of King Charles V and Joan of Bourbon. His reign was characterised by ceding territory to foreign powers and the creation of power struggles within the French aristocracy.

Background: The last of the great warrior kings of the Middle Ages, King Henry V ruled England for nine years and in that time managed to expand its empire significantly. His reign was characterised by military conquest and solid political and financial support from the English parliament and the country's barons. However, his reign did leave England in poor shape financially.

Agincourt battle map

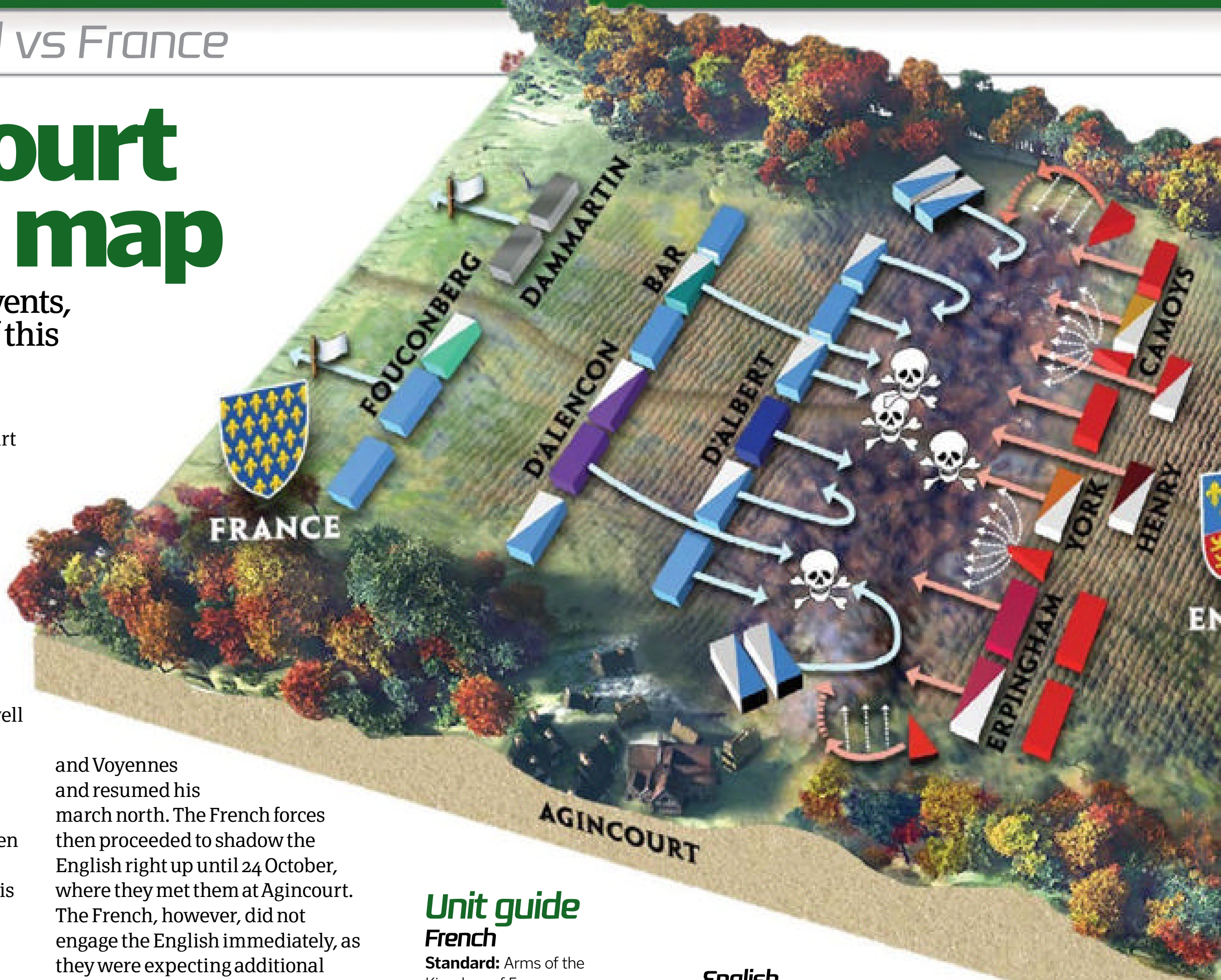
Discover the main events, tactics and terrain of this famous conflict

Contextually, the two sides approached the Battle of Agincourt from completely different directions – both literally and metaphorically. Henry had been campaigning in France since 13 August 1415, which had seen him besiege and take the port city of Harfleur and cover hundreds of miles through Normandy. As a result, the English forces were tired from fighting and marching, as well as suffering from food shortages, and disease was rife.

In contrast, the French had assembled a large army during Henry's taking of Harfleur at Rouen and then moved to block Henry's crossing of the River Somme on his march north to the English stronghold of Calais. The French forces were much fresher, substantial in number – with many nobles and soldiers alike amassed – and better equipped. All these factors led them to believe, quite understandably, that if a battle did happen, they would win decisively.

After being initially prevented from crossing the River Somme, Henry finally managed to cross it south of Péronne at Béthencourt and Voyennes and resumed his march north. The French forces then proceeded to shadow the English right up until 24 October, where they met them at Agincourt. The French, however, did not engage the English immediately, as they were expecting additional troops to arrive to support them. As such, the first day passed without incident, setting up 25 October as one of the most famous days in European military history.

For a blow-by-blow account of the battle, read through our chronological guide of the main events, which can be followed directly on the battle map.



Unit guide

French

Standard: Arms of the Kingdom of France

Men (estimate): 12,000-36,000

Archers and infantry: Blue 🟦

Cavalry: Blue and white 🟦⬜

Constable Charles d'Albret: Dark blue 🟦

Duke of Alençon: Purple 🟪

Duke of Bar: Turquoise 🟩

Count Fauconberg: Cyan 🟦

Count Dammartin: Silver ⬜

English

Standard: Royal Arms of England

Men (estimate): 6,000-9,000

Archers: Red triangle 🔺

Infantry: Pink 🟥

Cavalry: Red and white 🟥⬜

King Henry V: Maroon 🟫

Duke of York: Orange 🟧

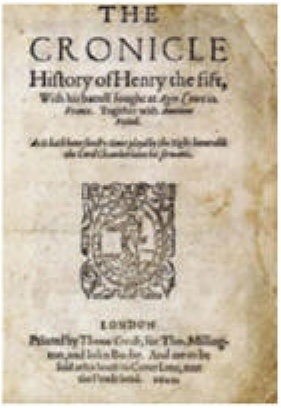
Sir Thomas Erpingham: Green 🟩

Baron Thomas de Camoys: Yellow 🟨

The turning of the tide

Shakespeare's dramatic re-enactment of the Battle of Agincourt in Henry V sends out some mixed messages

William Shakespeare's play *Henry V* (c. 1599) is interesting in its ambiguously polarised views on the battle, Henry himself, and war in general. On one hand, Shakespeare appears to praise military conquest and justify Henry's campaign – most notably in his famous St Crispin's Day speech, where Henry rallies his men. On the other hand, the play doesn't shy away from detailing the horrors of war and even closes with a reminder that, while Henry's victory won him the French throne, in the long term his son lost it and the battle was, historically, largely inconsequential.


THE
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LONDON

Step-by-step event guide

How did Henry V lead the English to victory?

1 Henry advances towards the French frontline, ordering his archers to uproot their defensive spear wall and replace it farther up the battlefield. This catches the French forces off-guard and they fail to charge before the spear wall is reinstated. English longbowmen in the central frontline begin bombarding the French with arrows.

2 While the French frontline try to quickly organise themselves for a frontal charge, Henry orders his flanking squads of longbowmen to move up the battlefield within the trees to the right and left, advancing to a point where they can fire from either flank into the centre of the French troops. Like the frontline archers, they set up spear walls.

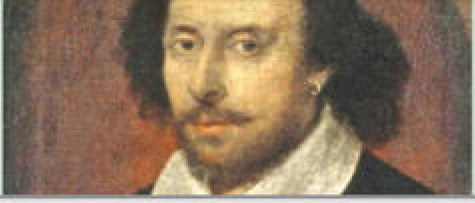
3 Constable D'Albret orders the French frontline to charge at the English frontline. They are met by multiple waves of arrows, which decimate large

STRANGE BUT TRUE

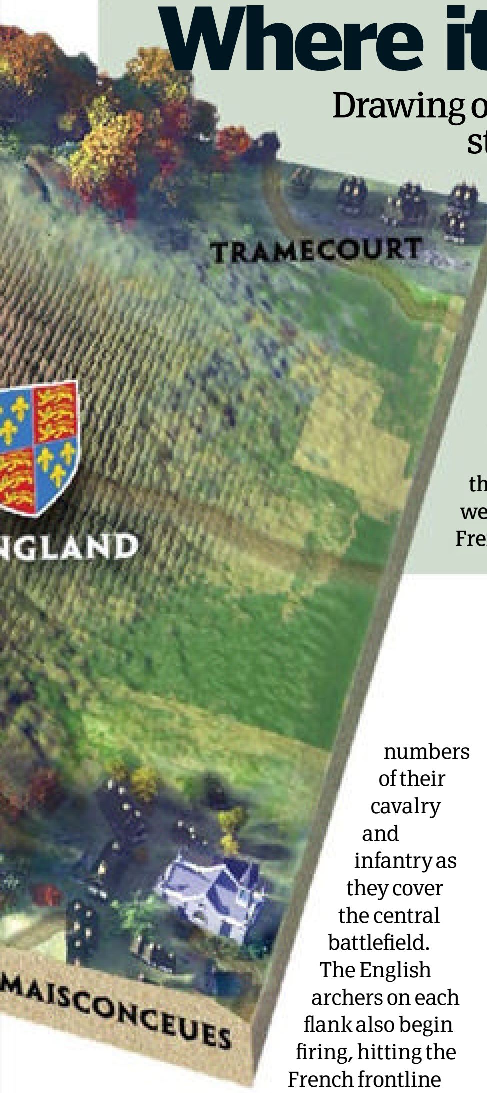
PLAY FIGHTING

BLOODLESS BATTLE

Despite Shakespeare's play *Henry V* revolving entirely around the Battle of Agincourt, the stage production actually features no depiction of combat whatsoever, focusing instead on events before and after the fighting.



DID YOU KNOW? As well as being famed for his military prowess, Henry V was also considered a shrewd political diplomat



numbers of their cavalry and infantry as they cover the central battlefield. The English archers on each flank also begin firing, hitting the French frontline from both sides.

4 D'Albret and limited numbers of the French frontline reach the English spear wall and begin to engage them in hand-to-hand combat, pushing it backwards. The longbowmen retreat and Henry orders his infantry to advance and meet the French.

5 Fierce, close-quarters fighting begins upon the sodden, muddy ploughed terrain at the centre of the battlefield. The combination of the dense mud and heavy armour worn by the French knights leads to thousands of them getting severely bogged down and exhausted, with the lighter-armoured English forces able to operate much more effectively.

6 D'Albret is suddenly killed in the melee, falling into the mud. Meanwhile, the French second line advances into the centre of the battlefield congesting it further. At this point the two side flanks of English archers abandon their ranged weapons and rush into the French second line from both the right and left.

7 The Duke of York is killed by a blow to the body and proceeds to get lost amid the sea of fighting soldiers. In addition, Henry's brother – Humphrey, the Duke of Gloucester – is wounded by a blow to the groin. Henry quickly moves to his position and defends him with his personal retinue – he succeeds but in the process receives a blow to the head that removes part of his crown.

8 The Duke of Bar is killed as his forces get depleted by the encircling English. Upon seeing the disaster that is unfolding before his eyes, the Duke of Alençon attempts to reach the English to submit a surrender notice, however he is killed by a blow to the head before it can be delivered.

9 The third line of French forces hovers on the outskirts of the battle, unsure whether to fight or not. Henry perceives they will and, due to the large number of unrestrained French prisoners from the first and second waves, orders all but the most high-ranking to be executed to prevent them from rearming en masse and overrunning the exhausted English.

10 Upon seeing the vast losses and executions, the French third line, led by the Counts Fauconberg and Dammartin, retreat to the rear, fleeing the battlefield. Henry wins the battle and orders a count of the dead, which reveals roughly 8,000 French troops had died compared to the English's 450.

Where it went wrong for the French

Drawing on the lessons of military history, we weigh up where Charles d'Albret's strategy foundered, and how the French might have won the battle

Key to Henry's victory was his good use of tactical positioning and Constable D'Albret's poor use of it. Indeed, with D'Albret's bigger and fresher force, he arguably should have won the battle if he had made a few key adjustments.

First, if D'Albret had engaged Henry's forces on a more open terrain, he would have been able to better utilise his large selection of cavalry, which during the skirmish could not outflank the English forces and so were forced to charge head-on.

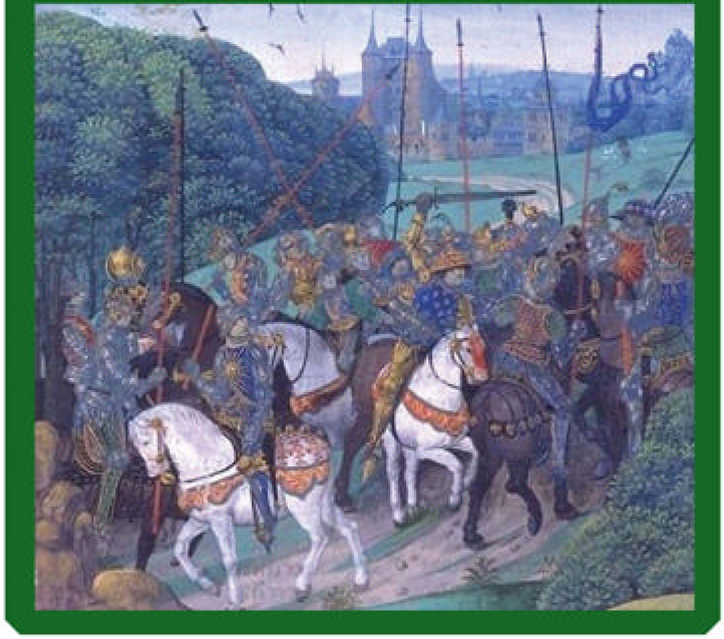
Second, D'Albret totally underestimated the damage that could be inflicted by the English longbowmen, who were the best archers in the world at the time. As such, French cavalry and infantry alike were continuously bombarded from the front and sides by Henry's well-placed units, severely decimating their troops before they even reached the English frontline. Once again, a more open terrain could have avoided this.

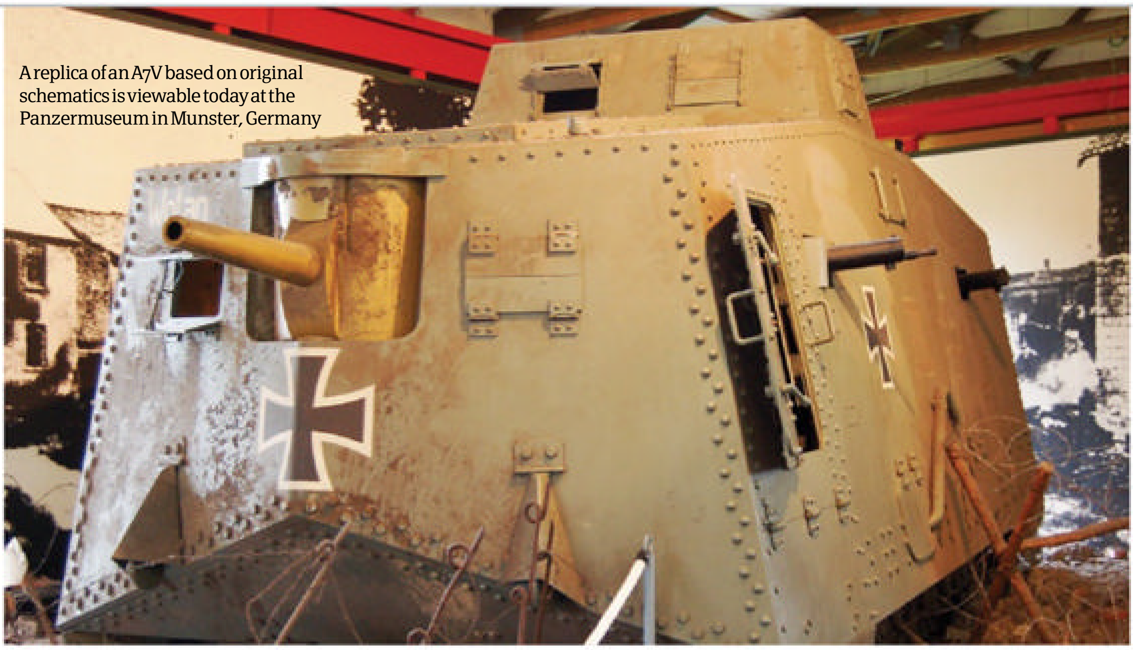
Third, and last, D'Albret's forces – notably the French army's noble knights – were outfitted in heavy armour. While such gear provided a greater degree of protection in hand-to-hand combat, it severely limited their movement and agility, something that would become fatal on the busy, muddy central battlefield. Indeed, reports indicate that the battlefield became so cramped and sodden that when knights were knocked down they struggled to even stand back up again, let alone efficiently engage the lighter-armoured, and so more agile, English troops.

The mad king

King Charles VI wasn't at Agincourt as his court considered him unstable, but was he?

Charles VI's reign was blighted by an apparent mental illness, which manifested itself in a series of conditions ranging from him believing he was made of glass to outright paranoia and violent episodes. One of the most notable of these episodes was during a march to Brittany from Paris to punish what Charles VI perceived to be a would-be assassin. After being warned by a passing leper that he should turn back as he was betrayed, he reportedly suddenly shouted, "Forward against the traitors! They wish to deliver me to the enemy!" and proceeded to hack down and kill several of his personal bodyguards (see picture below). After finally being dragged from his horse, Charles fell into a coma. As such, and especially towards the end of his reign, he was largely confined to his residence in Paris and – as a direct consequence – did not lead his forces at the Battle of Agincourt.





A replica of an A7V based on original schematics is viewable today at the Panzermuseum in Munster, Germany

The A7V

One of the earliest tanks to be produced, the A7V was supposed to deliver German soldiers a mobile fortress to break through Allied lines, but wasn't a great success…

Designed specifically to counter the emergence of British tanks on the Western Front during World War I, the A7V was a medium-armoured tank designed by the German General War Department in 1916. The vehicle resembled a mobile pillbox or APC (armoured personnel carrier) and delivered a steel-plated body for 18 soldiers, a 57-millimetre (2.2-inch) cannon and six to eight 7.9-millimetre (0.3-inch) machine guns (for a full hardware breakdown see 'Anatomy of an A7V' diagram). Its role, as hinted at by its German classification – Sturmpanzer-Kraftwagen translates roughly as 'assault armoured motor vehicle' – was to assault and break through fortified Allied lines.

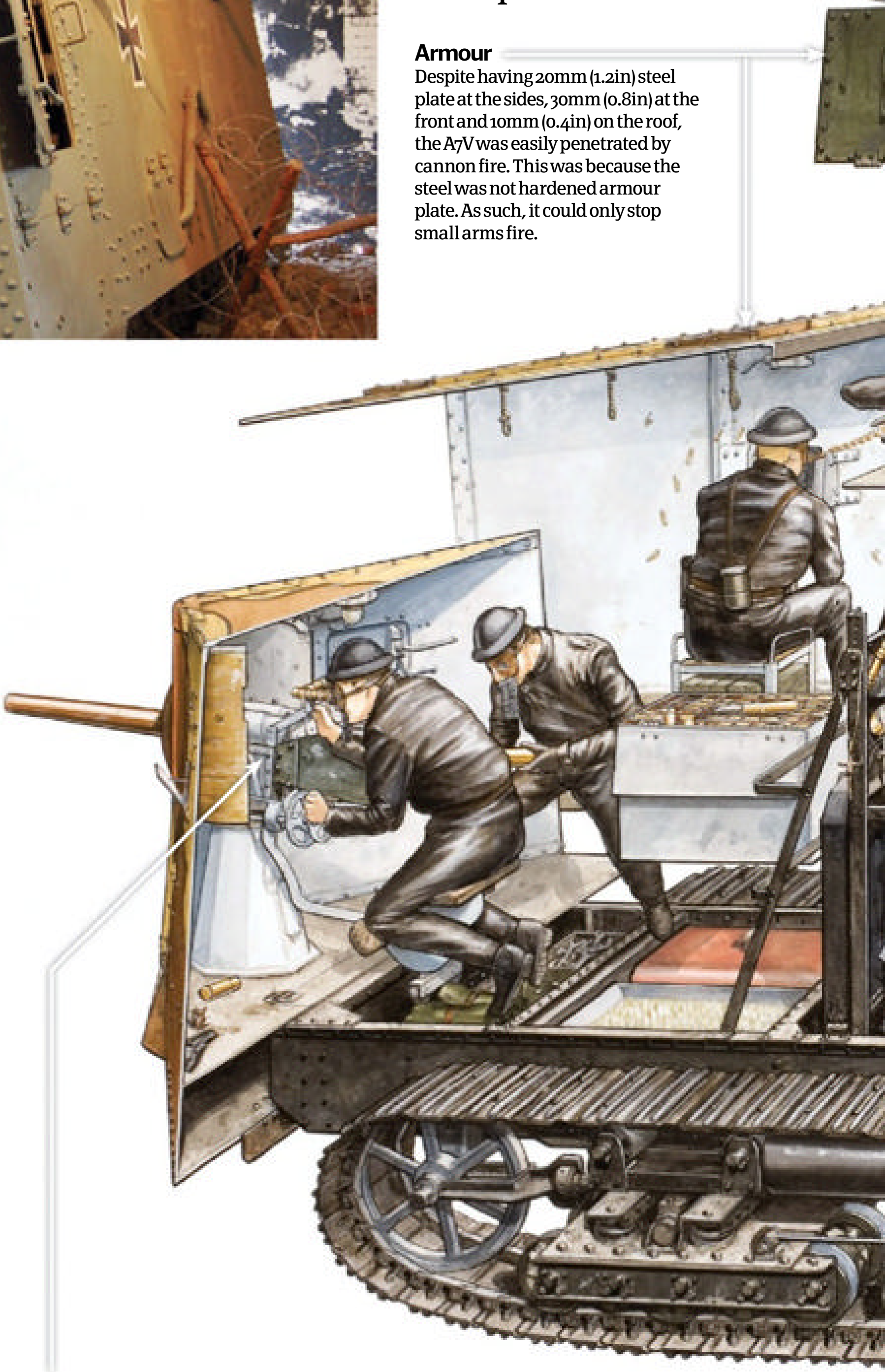
The first preproduction A7V was delivered in September 1917 and was closely followed by the first production model in October of the same year. Despite this, the first deployment of the A7V had to wait until March 1918, where five of the total 20 made were deployed north of the St Quentin Canal in northern France. Unfortunately, this is where the first design flaws of the vehicle were first encountered. Three of the five tanks broke down during operation due to mechanical faults.

Despite these issues, the A7V fleet was then deployed en masse, with 18 vehicles partaking in the Second Battle of Villers-Bretonneux in April 1918. Although reports from Allied soldiers at the time state that the A7V's armour made direct attack from their handheld weapons impossible, the A7V's modest armour was easily breached by the Allied Mark IV's six-pounder cannons. Further, due to the low clearance and crude design of the A7V's suspension and tracks, many got stuck on difficult off-road terrain and two even toppled over into holes. In addition, after a swift counterattack by Allied forces, three of the stranded A7Vs were captured.

As such, even though 100 A7Vs had originally been ordered, their limited impact led to the programme to be scrapped, with many of the remaining vehicles dismantled as early as October 1918. Today, no original A7V has survived, with the majority scrapped after the war. However, a replica based on original designs was built between 1987 and 1990 and can now be viewed by the public at the Panzermuseum in Munster, Germany.

Anatomy of an A7V

Take a look inside this World War I tank to see just how it was built and operated



Armour
Despite having 20mm (1.2in) steel plate at the sides, 30mm (0.8in) at the front and 10mm (0.4in) on the roof, the A7V was easily penetrated by cannon fire. This was because the steel was not hardened armour plate. As such, it could only stop small arms fire.

Armament
The main weapon of the A7V was a 57mm (2.2in) Maxim-Nordenfelt cannon, which was equipped to all male variants. The secondary armament was a series of six to eight 7.9mm (0.3in) MG08 machine guns. The tank could carry 180 shells for the cannon.

Suspension
The A7V was equipped with helical springs, rear-drive sprockets, front-mounted idlers and 24 roller wheels in bogies. The lack of shock absorbers made the ride incredibly bumpy and the low clearance (ie 190-400mm/ 7.5-15.7in) led to poor off-road capabilities.

5 TOP FACTS
A7V TRIVIA

Fortress
1 British forces nicknamed the A7V the 'Moving Fortress' when it was first deployed on the battlefield. This was due to its large pillbox design and heavy (for the time) armour.

Service
2 Due to its crude design and myriad problems, the A7V was only in operation for a total of seven months, from March to October 1918. Only replicas survive today.

Designer
3 The inventor of the A7V, Joseph Vollmer, was the chief designer for the German War Department. He went on to produce the K-Wagen, LK I and LK II tanks.

Female
4 The A7V had both male and female variants. The male had six machine guns and a 57mm (2.2in) cannon, while the female version replaced the cannon with two extra machine guns.

Wotan
5 One A7V, named Wotan, after being scrapped by the Allies in 1919 was rebuilt in the Eighties based on original designs. The replica now resides in the Panzermuseum, Germany.

DID YOU KNOW? In German the A7V was called the Sturmpanzer-Kraftwagen (which means assault armoured motor vehicle)

Crew
An A7V's crew consisted of 17 soldiers and one officer. These were needed for the following roles: commander, driver, mechanic, two artillery men (gunner and loader) and 12 infantry men (six gunners and six loaders).

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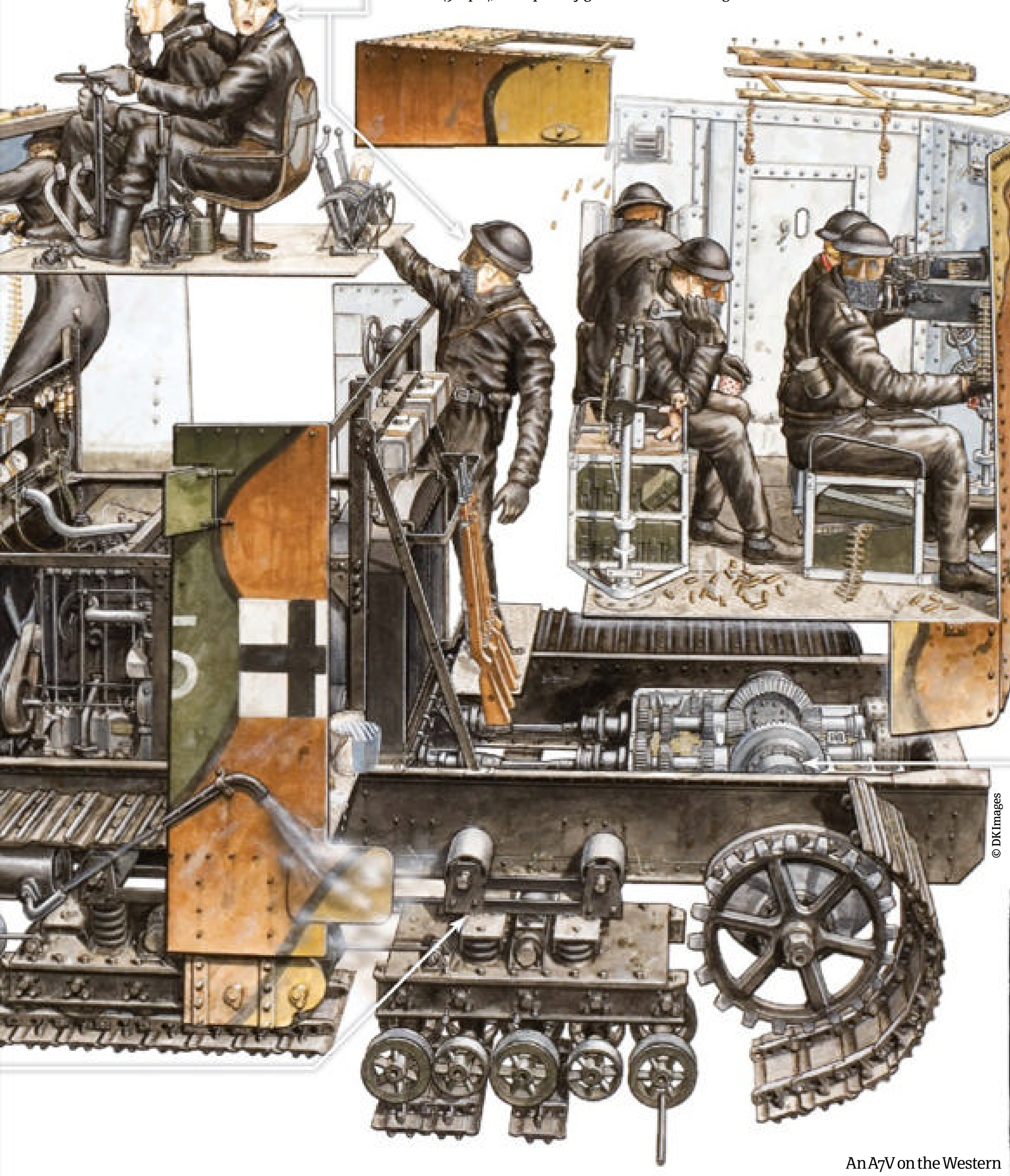
Despite the A7V being capable of travelling at 15km/h (9mph), it frequently got stuck on uneven ground

© Bundesarchiv, Bild 146-1974-050-12 / CC-BY-SA

A shot of an A7V and its crew from July 1918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The statistics...

A7V

Crew: 18

Height: 3.3m (11ft)

Width: 3.1m (10ft)

Length: 7.3m (24ft)

Weight: 30 tons

Engine: 2 x Daimler four-cylinder petrol (149kW/200hp total)

Suspension: Holt track, vertical springs

Max speed: 15km/h (9mph)

Max range: 80km (50mi)

Armour: Sides: 20mm (0.8in); front: 30mm (1.2in); roof: 10mm (0.4in)

Main armament: 57mm (2.2in) Maxim-Nordenfelt cannon

Secondary armament: 6 x 7.9mm (0.3in) MG08 guns

Engine
The A7V's power came courtesy of two centrally mounted Daimler four-cylinder petrol engines, each capable of generating 75kW (100hp). The engines were fed by a 500l (132ga) fuel tank. At full power, the A7V could travel at a maximum speed of 15km/h (9mph).

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An A7V on the Western Front in March 1918

Gunpowder What is it and how is it made?

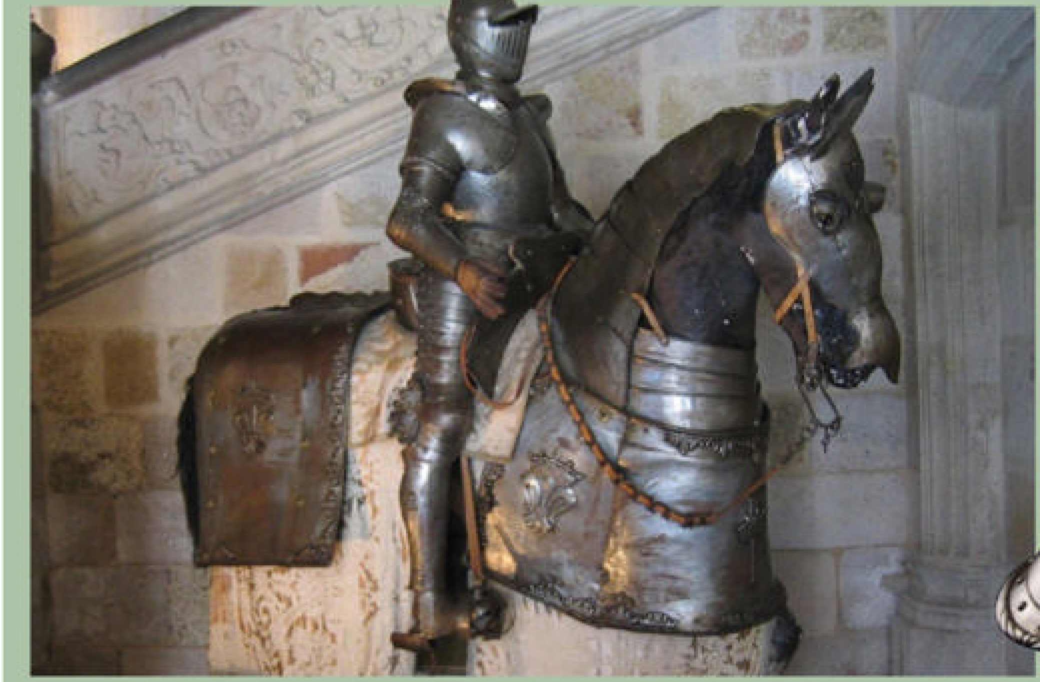
Gunpowder – also referred to as black powder – is made from potassium nitrate (75 per cent), sulphur (11 per cent) and charcoal (14 per cent). When these three materials are ground finely and combined, the resultant mixture burns quickly and produces a mix of gaseous and solid by-products. The mixture is relatively insensitive to shock and friction, requiring high levels of heat to be ignited. However, when ignited in a confined space – such as in the breech of a weapon – the released gases generate enough pressure to launch projectiles, hence its widespread use in armaments. While still used today in ignition charges, fuses and primers, gunpowder is no longer widely used as a propellant for guns and cannons, being replaced with smokeless powders that grant higher muzzle velocities due to their progressive burns (they generate more and more gas pressure throughout the combustion process).

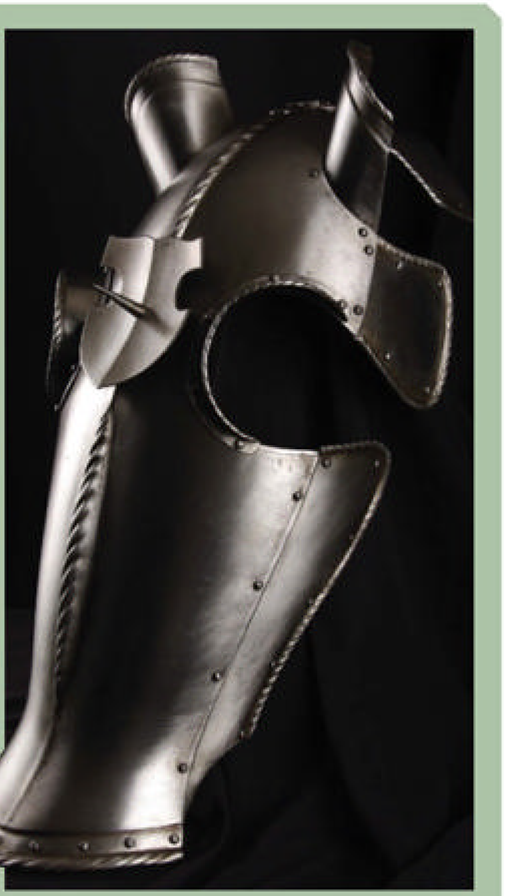
Potassium nitrate (75%)
Charcoal (14%)
Sulphur (11%)

Gunpowder is made from a mix of materials

Horse armour explained

If you thought it was only the knights who were protected from head to toe during battle, it's time to think again…





Medieval combat largely revolved around mounted engagements, with cavalry playing a crucial role in the majority of battles. Keeping horses alive and in good condition was therefore imperative to success, with arrows, spears and swords often targeting the animal over the rider due to the knight's extensive armour.

As such, armour for horses (known as barding) became increasingly prevalent through the 14th and 15th centuries and grew in both stature and complexity until horses were equipped with a variety of battle gear.

Armour plates included: a champron – a type of helmet worn to protect the horse's head; a crinière, which was a series of armour plates that encircled the animal's neck; and a breastplate called a peytral. It would also have a pair of flanchards, which were two armoured panels that sat either side of the knight's saddle as well as a croupiere – a large plate or chain dome that would shield the horse's hindquarters.

Combined, these pieces of armour left very little of the horse's body exposed, allowing it to charge through volleys of arrows without being compromised. It was only vulnerable to well-placed spear or sword incisions, which were incredibly difficult to achieve if you were being charged down at speed!

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5 TOP FACTS
F-4 PHANTOM

Spooky
1 The Phantom's emblem was a whimsical cartoon ghost referred to as 'The Spook' by pilots. It was designed by McDonnell Douglas technical artist Anthony Wong.

Nicknames
2 The Phantom acquired a number of nicknames during its long career including the Rhino, Flying Anvil, Flying Footlocker, Lead Sled and the St Louis Slugger.

Export
3 The Phantom was not only used in North America but also in many other national militaries, being exported to Greece, Germany and Iran to name just a few countries.

Angels
4 The F-4J Phantom II variant also saw plenty of non-military action. For instance, it was flown by the US aerobatic display team, the Blue Angels, from 1969 through to 1974.

Obsolete
5 The F-4 Phantom II was eventually superseded by a brace of newer fighter jets from the Eighties onwards. These included F-14 Tomcats and F/A-18 Hornets.

DID YOU KNOW? *The F-4 Phantom II was officially introduced on 30 December 1960*

Inside the F-4 Phantom II

One of the most iconic fighter planes ever, the F-4 Phantom II set 15 world records during its lifetime

The F-4 was one of the most technologically advanced fighter-interceptors of its generation. Breaking numerous records – highest-altitude flight, fastest flight speed and fastest zoom climb to name but a few – and introducing advanced new construction materials and aviation features, the jet ruled the skies from 1960 up until the end of the Seventies.

The Phantom was powered by a pair of General Electric J79 axial compressor turbojets, which could deliver a whopping 8,094 kilograms-force (17,845 pounds-force) of thrust in afterburner. This, along with its super-strong titanium airframe, granted the aircraft a lift-to-drag ratio of 8.58, a thrust-to-weight ratio of 0.86 and a rate of climb north of 210 metres (689 feet) per second. That extreme amount of power also afforded it a top speed of 2,390 kilometres (1,485 miles) per hour.

As a fighter-interceptor, the F-4 was equipped with nine external hardpoints. Air-to-air AIM-9 Sidewinders, air-to-ground AGM-65 Mavericks and anti-ship GBU-15s, as well as a Vulcan six-barrelled Gatling cannon, were but a small selection of the heavy-duty weaponry available. In addition, it was also specified to carry a range of nuclear armaments.

Perhaps the biggest innovation delivered by the F-4 Phantom II, however, was the adoption of a pulse-Doppler radar. Still in use today, this is a four-dimensional radar system that's capable of detecting a target's 3D position and its radial velocity. It does this by transmitting short bursts of radio waves (rather than a continuous wave), which after being partially bounced back by the airborne object, are received and decoded by a signal processor, which discerns its location and flight path through the principles of the Doppler effect.

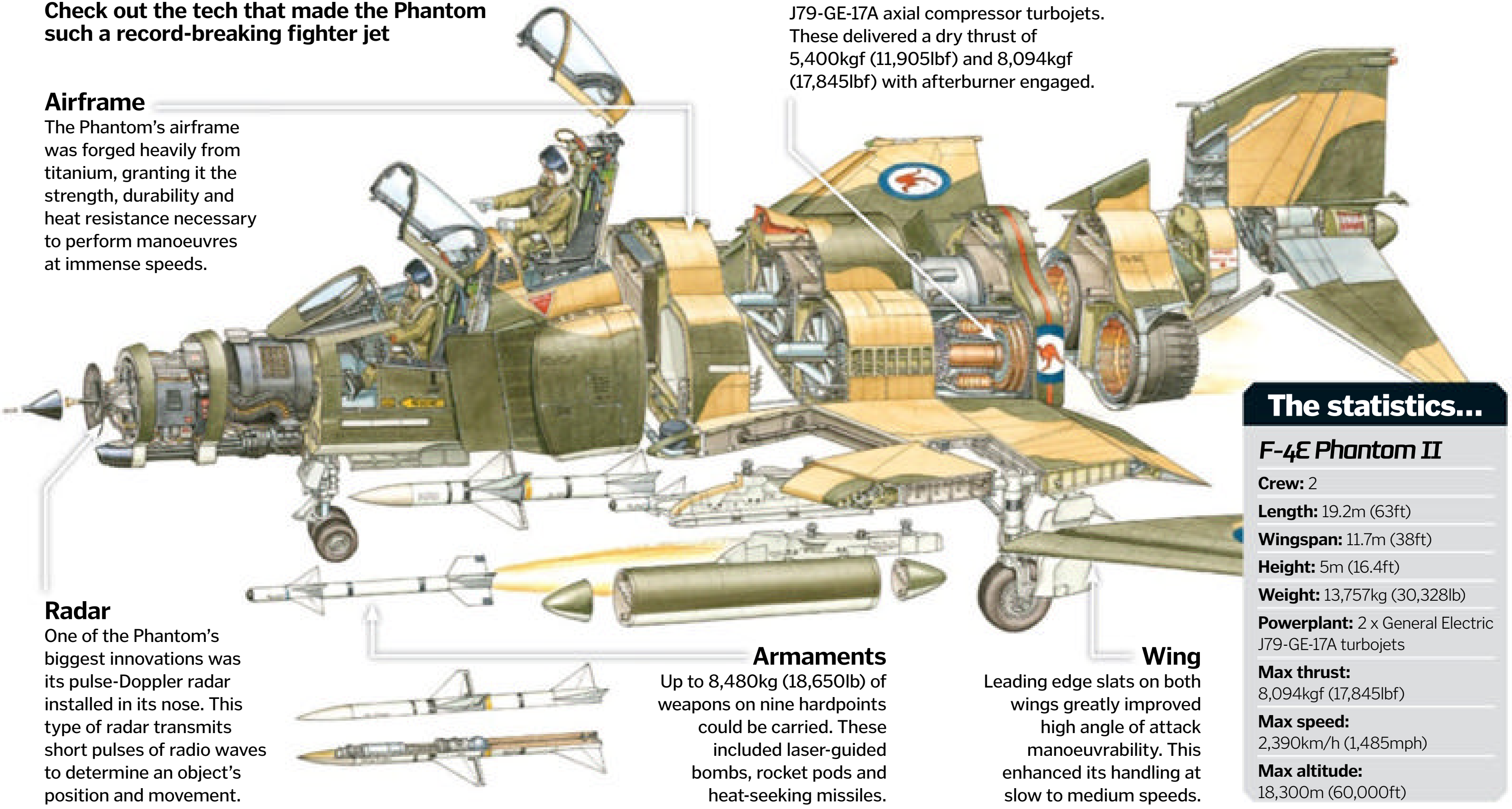
Nine external hardpoints could be installed offering an arsenal of heavy firing power

Anatomy of an F-4E Phantom II

Check out the tech that made the Phantom such a record-breaking fighter jet

Airframe
The Phantom's airframe was forged heavily from titanium, granting it the strength, durability and heat resistance necessary to perform manoeuvres at immense speeds.

Powerplant
The F-4E was equipped with two GE J79-GE-17A axial compressor turbojets. These delivered a dry thrust of 5,400kgf (11,905lbf) and 8,094kgf (17,845lbf) with afterburner engaged.



Radar
One of the Phantom's biggest innovations was its pulse-Doppler radar installed in its nose. This type of radar transmits short pulses of radio waves to determine an object's position and movement.

Armaments
Up to 8,480kg (18,650lb) of weapons on nine hardpoints could be carried. These included laser-guided bombs, rocket pods and heat-seeking missiles.

Wing
Leading edge slats on both wings greatly improved high angle of attack manoeuvrability. This enhanced its handling at slow to medium speeds.

The statistics…

F-4E Phantom II

Crew: 2

Length: 19.2m (63ft)

Wingspan: 11.7m (38ft)

Height: 5m (16.4ft)

Weight: 13,757kg (30,328lb)

Powerplant: 2 x General Electric J79-GE-17A turbojets

Max thrust: 8,094kgf (17,845lbf)

Max speed: 2,390km/h (1,485mph)

Max altitude: 18,300m (60,000ft)

© DK Images; Alamy

Jousting explained

High-speed, brutal and theatrical – it's easy to see why this martial sport was so popular in the Middle Ages

Jousting was a martial sporting event undertaken between two horsemen using lances, each aiming to strike the other and unhorse him. It worked either as a single event or as part of a larger tournament, the latter involving other athletic disciplines such as hand-to-hand combat.

The joust itself, however, worked on a point-scoring system, with each true blow struck on the opponent generating a number of points for the striker, the total depending on where the blow landed. So, if a rider hit his opponent on the helmet he was awarded two points, while if he struck them on the breastplate only a single point would be awarded. If a rider unhorsed his opponent with a strike then he was awarded three points and the match was considered over. Importantly, however, only true blows generated points, with a true blow consisting of the lance shattering on impact. Glancing blows, low blows and any strike that did not shatter the lance were not counted.

For each joust both horsemen were equipped with a trio of lances, to be used over a series of three charges. All lances were measured before each joust to ensure they were of equal length and therefore no reach advantage could be sought. In addition, strict rules governed each meeting, with only the horseman's squire (assistant) allowed to hand him new lances or help him in the event of an unhorsing. As part of these rules, it was also mandatory that any knight competing own the horse and armour he was using, as in the event that they were unhorsed, their opponent could demand both as a victory trophy. Of course, all these rules came behind the first and most important, which stated that only noblemen could compete.

If the joust was held as part of a larger competition, the other key event was the hand-to-hand combat match. This worked along a similar set of rules to the joust proper, with the first knight to land three blows on his opponent the victor. Which weapons and styles were allowed were dictated before the tournament.

Historically, jousting emerged out of the High Middle Ages (1000-1300) and was based on the military use of the lance by heavy cavalry. Up until the 17th century, jousting gradually evolved from a blood sport into the sporting form of chivalry for

5 TOP FACTS JOUSTING

Jousting jeopardy

1 Jousting tournaments in the High Medieval period were considerably rougher and more dangerous than the more chivalric events held in the Late Medieval period.

A question of honour

2 By the 1390s combat in jousts was generally expected to be non-lethal, with any defeated opponent expected to honourably yield to the more dominant fighter.

Beyond the main event

3 Despite the main event in any jousting tournament being the joust proper, there were other subsidiary events, including foot combat, with the first to land three blows the winner.

Etymology

4 The term 'joust' is believed to have derived from the Old French word 'joster', which itself is derived from the Late Latin 'iuxtare', meaning to approach and/or to meet.

Lance-a-lot

5 Jousting lances were often made from ash wood, however unlike their military predecessors, they were not fitted with sharp iron or steel tips but rather blunt ones.

DID YOU KNOW? *Jousting was phased out in France after King Henry II was mortally wounded in a tournament in 1559*

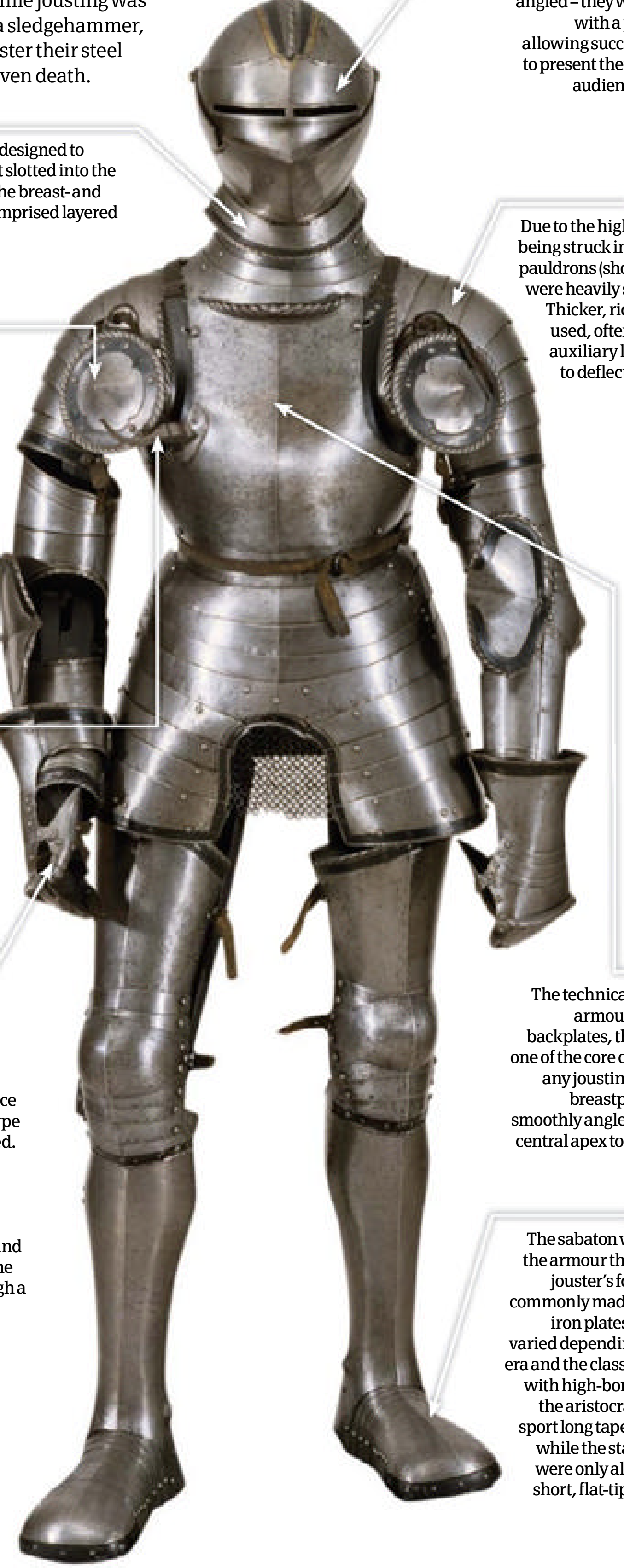
which it is now remembered. For example, by the time of Queen Elizabeth I's reign (1558-1603), jousting had been heavily romanticised and was known more as a form of entertainment, rather than proof of military prowess.

Interestingly, today jousting is seeing something of a renaissance, with dedicated jousting clubs organising competitions and medieval re-enactment events held worldwide.

> *"Only true blows generated points, with a true blow consisting of the lance shattering on impact"*

Jousting armour breakdown

Being hit with a lance while jousting was akin to being struck by a sledgehammer, requiring knights to bolster their steel plate to avoid injury or even death.



Helmet
Due to bonus points being awarded for a head strike, jousting helmets were heavily modified to add more protection. Armets and close helms were popular, as – aside from being sharply angled – they were equipped with a pivoting visor, allowing successful knights to present themselves to the audience post-battle.

Gorget
The gorget was a steel collar designed to protect the knight's throat. It slotted into the suit of armour underneath the breast- and backplates, and typically comprised layered and angled steel plates.

Pauldron
Due to the high likelihood of being struck in the shoulder, pauldrons (shoulder guards) were heavily strengthened. Thicker, ridged steel was used, often with a fluted auxiliary layer designed to deflect lance strikes.

Besagew
Due to reduced necessity of movement while charging in horseback jousts, knights would often equip besagews (small circular shields) to their armour. These were designed to provide extra protection at joints – such as the armpit – where gaps in the plate could be exploited.

Lancer
A unique adaptation to standard plate armour was a lance holder, which was positioned beneath the right-arm pauldron. The steel hook was welded to the breastplate and helped support the lance while charging, allowing for a greater strike accuracy.

Cuirass
The technical name for the armour's breast- and backplates, the cuirass was one of the core components to any jousting armour. The breastplate was often smoothly angled away from a central apex to deflect blows.

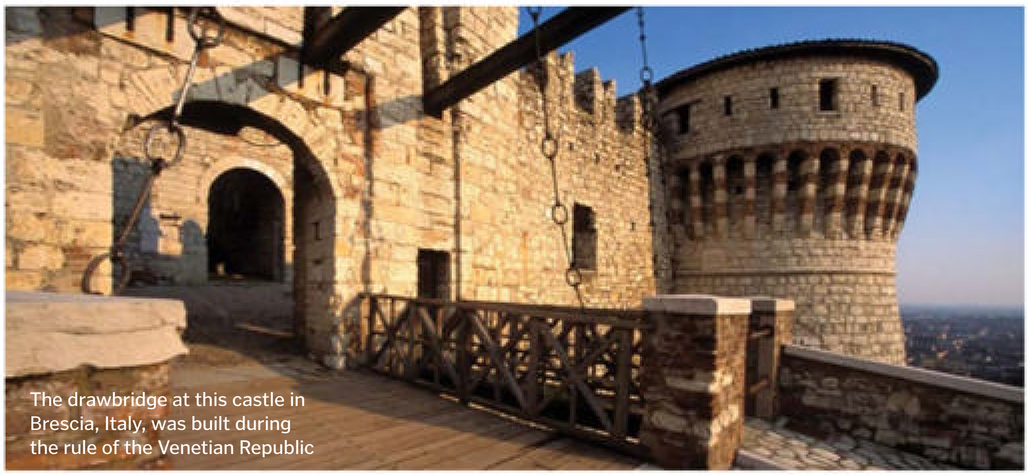
Gauntlet
Jousting gauntlets were designed to maximise the combatant's grip of their lance and, as such, Almain rivet type designs were commonly used. These consisted of layered, overlapping steel plates augmented with reinforced knuckle and fingertip caps, which covered only the top and sides of the hands, leaving the underside free to grip through a leather/fabric glove.

Sabaton
The sabaton was the part of the armour that covered the jouster's foot. They were commonly made from riveted iron plates. Their design varied depending both on the era and the class of the jouster, with high-born members of the aristocracy allowed to sport long tapered sabatons, while the standard gentry were only allowed to wear short, flat-tipped varieties.

How drawbridges worked

Used to defend castles for centuries, these fold-up entrances were simple yet effective

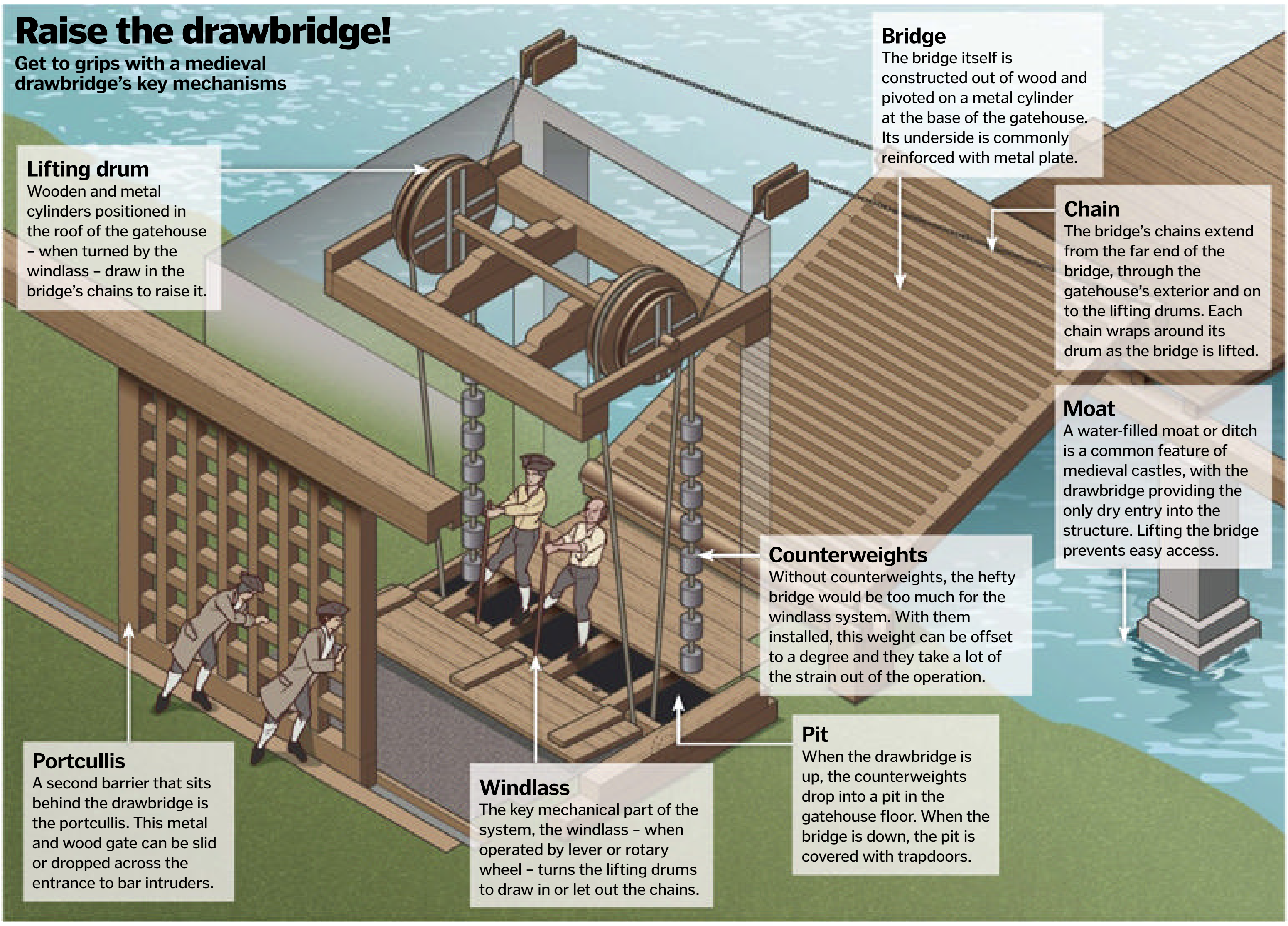
Classical, medieval drawbridges worked via the simple principle of counterweight, with large wood and metal bridges pivoted via a series of balancing weights in a castle's gatehouse. The weights, which were attached to the bridge's lifting chains, enabled the platform to be raised via a windlass, which in turn rotated a pair of lifting drums that gathered in the chains. By employing counterweights, incredibly heavy bridges could be operated by just a few people – useful when under attack. Along with a moat, a reinforced drawbridge served as a two-fold barrier, making it much more difficult for any enemies to invade a fortification or city.



The drawbridge at this castle in Brescia, Italy, was built during the rule of the Venetian Republic

Raise the drawbridge!

Get to grips with a medieval drawbridge's key mechanisms



Lifting drum
Wooden and metal cylinders positioned in the roof of the gatehouse – when turned by the windlass – draw in the bridge's chains to raise it.

Bridge
The bridge itself is constructed out of wood and pivoted on a metal cylinder at the base of the gatehouse. Its underside is commonly reinforced with metal plate.

Chain
The bridge's chains extend from the far end of the bridge, through the gatehouse's exterior and on to the lifting drums. Each chain wraps around its drum as the bridge is lifted.

Moat
A water-filled moat or ditch is a common feature of medieval castles, with the drawbridge providing the only dry entry into the structure. Lifting the bridge prevents easy access.

Counterweights
Without counterweights, the hefty bridge would be too much for the windlass system. With them installed, this weight can be offset to a degree and they take a lot of the strain out of the operation.

Portcullis
A second barrier that sits behind the drawbridge is the portcullis. This metal and wood gate can be slid or dropped across the entrance to bar intruders.

Windlass
The key mechanical part of the system, the windlass – when operated by lever or rotary wheel – turns the lifting drums to draw in or let out the chains.

Pit
When the drawbridge is up, the counterweights drop into a pit in the gatehouse floor. When the bridge is down, the pit is covered with trapdoors.

© Alamy/Peters & Zabransky

RECORD BREAKERS
A LONG WAY DOWN

1,357.6km/h

FASTEST FREE FALL

Felix Baumgartner became the first human to freefall faster than the speed of sound when he hit 1,357.6km/h (843.6mph) during his Stratos jump on 14 October 2012.

DID YOU KNOW? There are 20 quills laid out every day the US Supreme Court is in operation

Flint weapons

How human tool and weapon manufacturing first began

A selection of Stone Age flint weapons including arrowheads and spearheads

Before metals were first extracted during the Bronze Age, tools and weapons were made out of stone. A fundamental material used in the Stone Age was a sedimentary rock known as flint. Strong and with sharp edges, flint is plentiful in chalk and limestone beds around the world, which made it ideal for the first primitive tools and weapons. The stone was first mined over a million years ago during the Paleolithic period, using an extraction method known as flintknapping. This would involve chipping away at the seam of rock until the desired shape of blade was created. Some of the earliest flint tools were hand axes, which were used to hunt animals, chop wood, dig and even start a fire. Early weapons were big and blunt while later arms were better crafted, polished and sharper. From these primitive beginnings would arise the first daggers, spears and arrowheads, becoming an integral part in Stone Age warfare, toolworking and hunting.

The age of stone

The eras in which flint was a major component

Paleolithic period

Approx 2.5 million years ago

Flint tools of this age were at their most primitive with only basic tools like hand axes made. This type of toolwork was used by Homo erectus as well as Homo sapiens.

Mesolithic period

Approx 15,000 years ago

Tools became more sophisticated in this era, being used in carpentry to make the first structures. The first pottery was made in this period, in no small part due to this evolution.

Neolithic period

Approx 12,000 years ago

Emerging agriculture was the influence on the tools of this age with scythes made to harvest grain. Tools of this era also had a distinctive appearance due to increased polishing.

Breaking the sound barrier

What was the first thing to go faster than sound?

The first time that magical speed of 1,225 kilometres (761 miles) per hour was breached dates back to the Ancient Egyptians. They are one of the first civilisations recorded as using a whip, which has been creating sonic booms for over 4,000 years.

Lifting a whip and bringing it down sharply causes a ripple to move down the length of the whip as it rises up then snaps back down. As the wave moves along, it gets faster as the whip gets thinner. This continues until it reaches the tip and the thinnest part of the whip. If you have done it right, by this point the wave is moving so fast that the tip breaks the sound barrier as it flicks up, creating that characteristic crack.

Incidentally, the first human to travel faster than sound was US Air Force Captain Chuck Yeager as he flew an X-1 plane at Mach 1 – the speed of sound – in 1947.

> *"As the wave moves along, it gets faster as the whip gets thinner"*

©Alamy; Dreamstime

The first telephone
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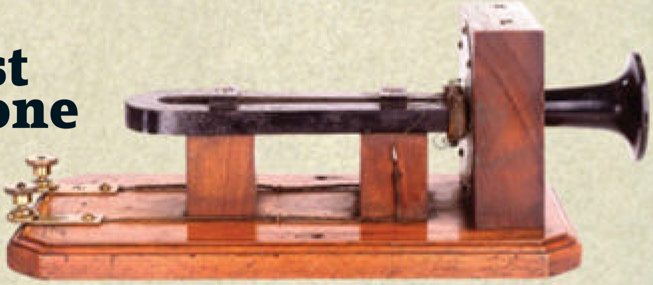

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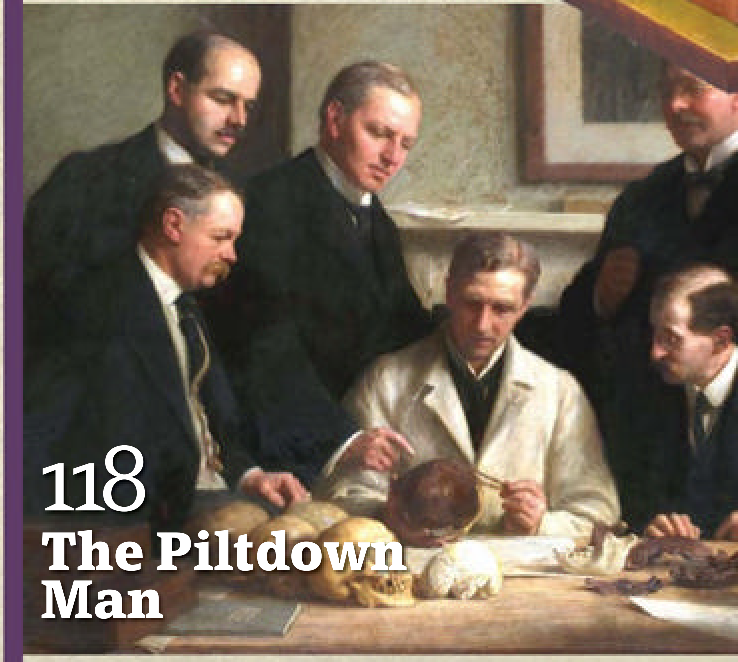

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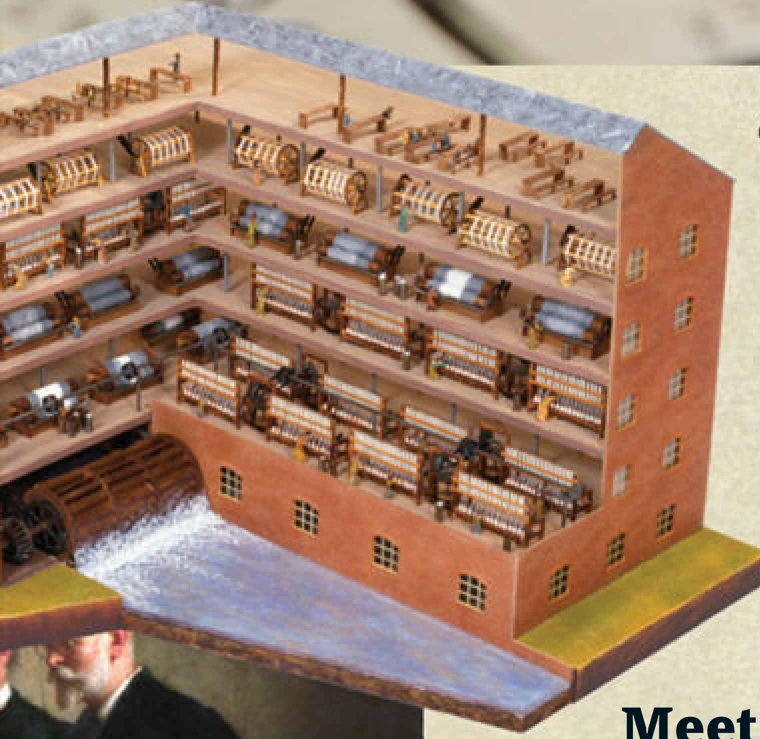

Meet Madame Guillotine
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123 **What are life-preserving coffins?**
How did this odd casket save anyone buried alive?

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Inside the world's first commerical portable and personal stereo cassette player

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Discover the main components of the first commercial fridges

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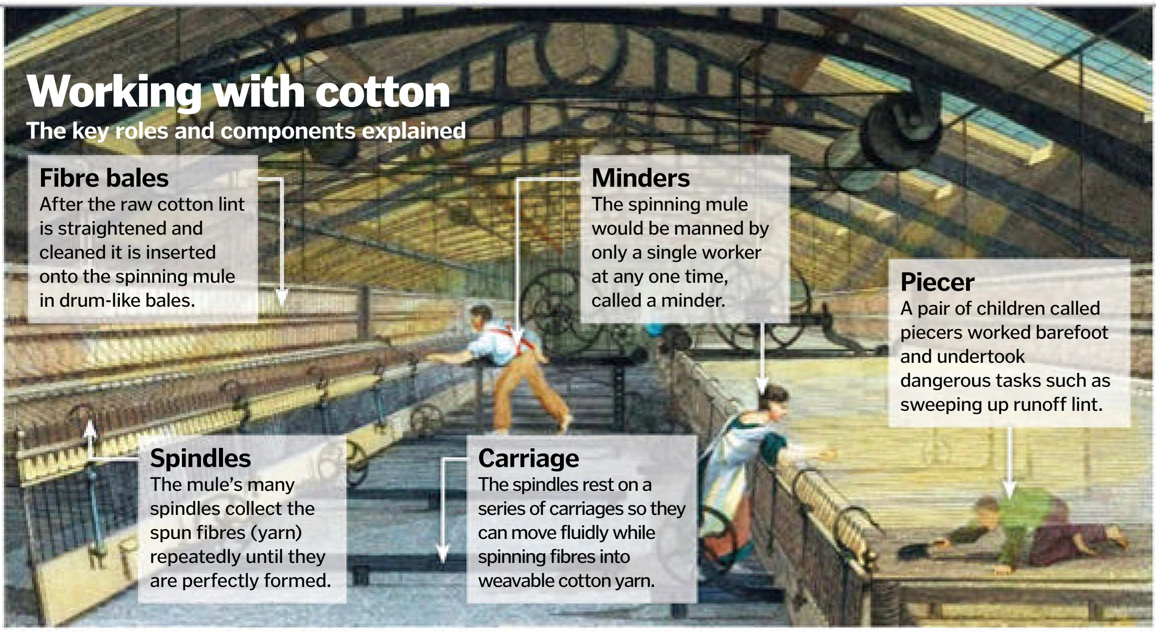


Working with cotton

The key roles and components explained

Fibre bales
After the raw cotton lint is straightened and cleaned it is inserted onto the spinning mule in drum-like bales.

Minders
The spinning mule would be manned by only a single worker at any one time, called a minder.

Piecer
A pair of children called piecers worked barefoot and undertook dangerous tasks such as sweeping up runoff lint.

Spindles
The mule's many spindles collect the spun fibres (yarn) repeatedly until they are perfectly formed.

Carriage
The spindles rest on a series of carriages so they can move fluidly while spinning fibres into weavable cotton yarn.

Inside a cotton mill

Understand the workings of one of the cornerstones of the Industrial Revolution and how cotton changed the world

In the 19th century, cotton production was one of the most profitable enterprises around. Western society had long been split into a two-tier system, with the aristocracy controlling over 90 per cent of the nation's wealth, with the rest left virtually penniless. The Industrial Revolution changed that, with a new merchant middle-class becoming a significant financial power.

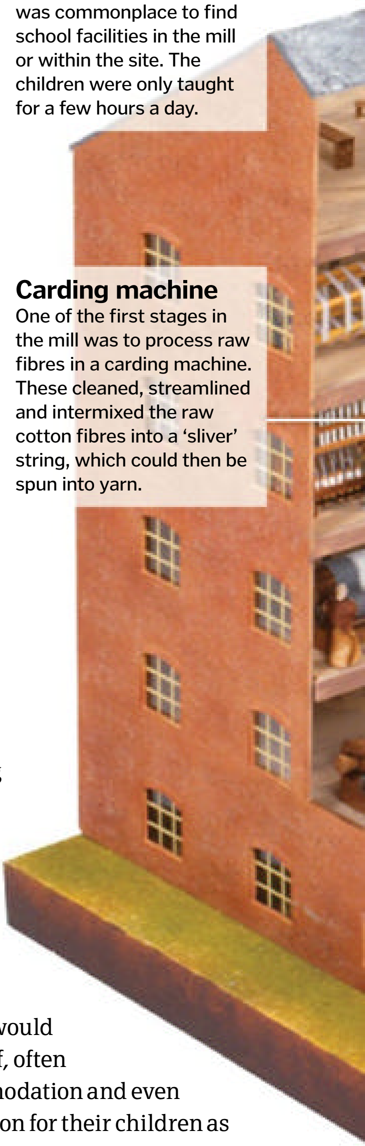
With the middle class's ascension came an increased need for quality fabric products. But while the need for cotton had grown, the cotton industry itself was still largely restricted to a series of cottage industries – small home-grown businesses staffed by manual labourers who were unable to keep pace with demand. Luckily, automated machines such as the self-actuating spinning mule and power loom were invented that enabled cotton to be processed, spun and woven at a scale that not only could meet demand but also rendered these cottage industries obsolete.

And so was born the cotton mill. These were staffed with the remnants of the former cottage industries as well as hundreds and thousands of others, with workers no longer required to hold proficiency in traditional skills such as sewing but instead simply be capable of operating the machines that now did everything for them.

Conditions were poor for the workers, with people of all ages – including children – exposed to potentially crippling machines as well as hot and dusty conditions that often led to fatal ailments. Workers frequently lost fingers and even limbs while operating the machinery too.

Despite the dire conditions, the sheer number of jobs available – to women and men alike, granting the former an independent income – saw the working class flock to cotton mills, with people often travelling across the country to cotton hotspots like Lancashire to earn some money. Many mill owners also offered packages that, before that point, the working class simply would never have dreamed of, often including free accommodation and even a rudimentary education for their children as an incentive to work there.

As the Industrial Revolution came to a close, the industry went into decline. By the early-20th century, cotton yarn and fabrics were now being produced all over the world, with new industrial heartlands emerging in Asia. This meant that by 1950 the age of the cotton mill was over, with its once bustling rooms falling silent.



Mill school
As most mill owners offered a basic education to their employees' children, it was commonplace to find school facilities in the mill or within the site. The children were only taught for a few hours a day.

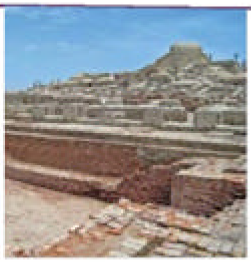
Carding machine
One of the first stages in the mill was to process raw fibres in a carding machine. These cleaned, streamlined and intermixed the raw cotton fibres into a 'sliver' string, which could then be spun into yarn.

A stitch in time…

Follow the key developments in the history of cotton with this quick timeline

5000 BCE
Treated cotton bolls and pieces of cotton cloth in Mexican caves date to around 7,000 years ago.

3000 BCE
The Harappan civilisation in what is Pakistan today grows, spins and weaves cotton during the Bronze Age.



800 CE
Arab merchants begin importing Eastern-made cotton into Europe in large quantities for the first time.

1500
Cotton is now used throughout the world. Its production remains restricted to cottage industries though.

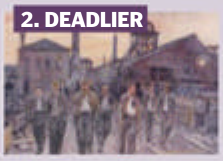
HEAD2HEAD

FATAL FACTORIES

1. DEADLY

Textile factory

With powerful machines designed to shred and tear, a tiny lapse in concentration could mean losing a limb, potentially dying from blood loss or infection.



2. DEADLIER

Coal plant

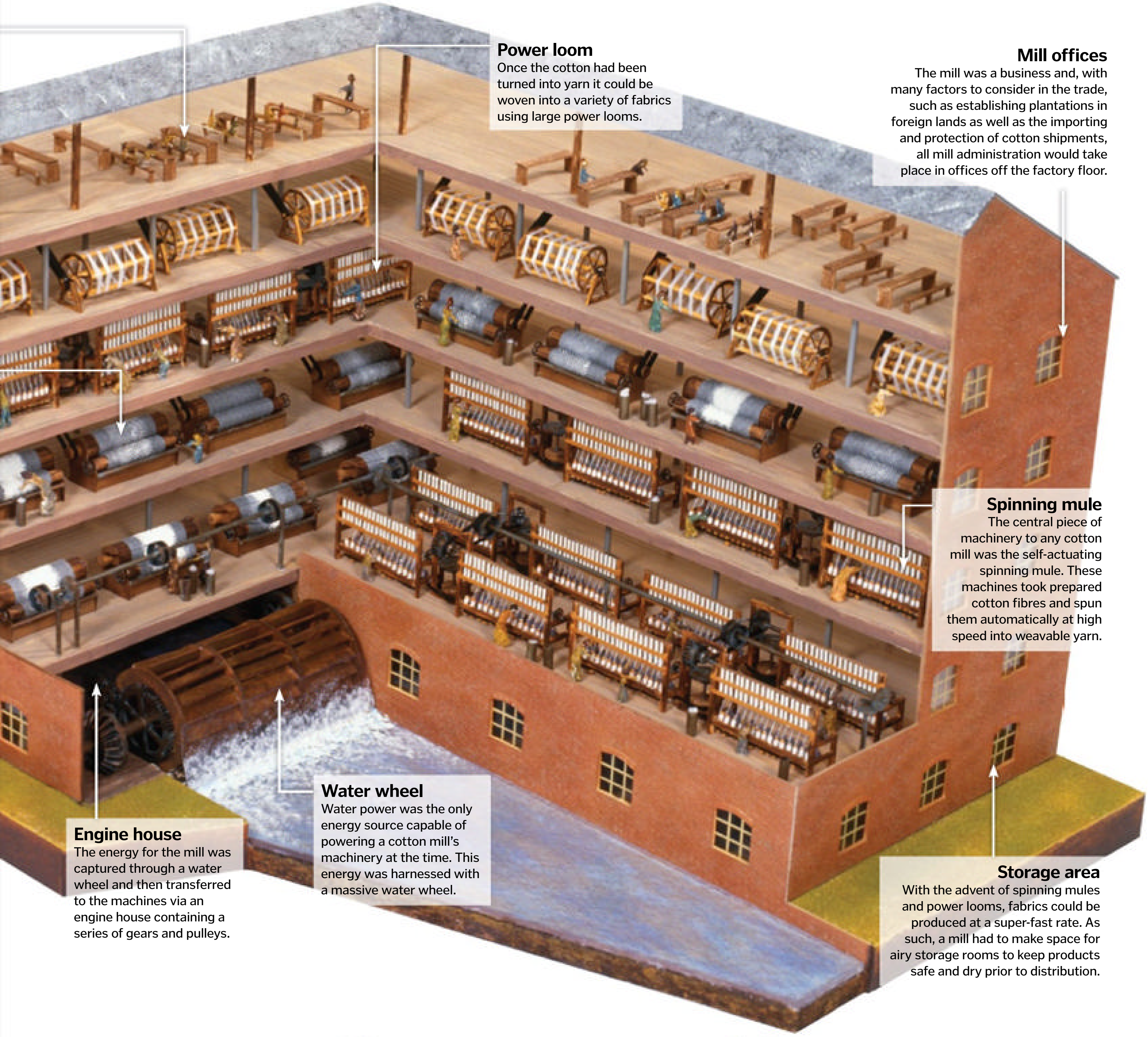
Extracting coal from mines was bad enough, but workers who processed it in poorly ventilated factories often died young from lung diseases too.

3. DEADLIEST

Metallurgy forge

The production of metals in super-hot and insanely hazardous furnaces inevitably led to many horrific burns and deaths.

DID YOU KNOW? *In 1833, England's largest cotton mill employed over 1,500 people*



Power loom

Once the cotton had been turned into yarn it could be woven into a variety of fabrics using large power looms.

Mill offices

The mill was a business and, with many factors to consider in the trade, such as establishing plantations in foreign lands as well as the importing and protection of cotton shipments, all mill administration would take place in offices off the factory floor.

Spinning mule

The central piece of machinery to any cotton mill was the self-actuating spinning mule. These machines took prepared cotton fibres and spun them automatically at high speed into weavable yarn.

Water wheel

Water power was the only energy source capable of powering a cotton mill's machinery at the time. This energy was harnessed with a massive water wheel.

Engine house

The energy for the mill was captured through a water wheel and then transferred to the machines via an engine house containing a series of gears and pulleys.

Storage area

With the advent of spinning mules and power looms, fabrics could be produced at a super-fast rate. As such, a mill had to make space for airy storage rooms to keep products safe and dry prior to distribution.

1730
The first machines to automatically process and spin cotton are put into use.

1741
The world's first mill designed to spin cotton mechanically is opened by English engineers Lewis Paul and John Wyatt.

1794
US inventor Eli Whitney patents the 'cotton gin', a machine that can separate cotton fibres from their seeds.

1824
English inventor Richard Roberts creates his most famous machine, the spinning mule, which can spin cotton at a rate unimaginable to manual spinners.

1855
In the mid-19th century cotton production enters a golden age, with huge mills being built.

1950
100 years on many mills have closed and those that survive become increasingly automatic, with electric engines.

© DK Images; Getty; Grjatoi

Medieval writing equipment

Why we used quills for over 1,300 years

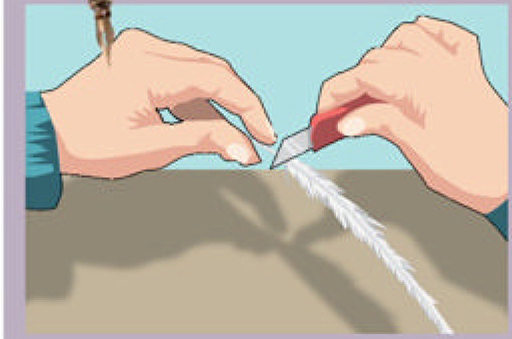
Before the invention of the pen, most people used quills to write with. These were stripped bird feathers, usually from geese. Swan feathers were very sought after but geese, crow, owl and turkey feathers were more simpler to obtain.

Quills were easy to supply, comfortable to hold and tapered down to a point so the writer could create all the subtle curves and lines of fine handwriting.

The first record of their use was around the 6th century by European monks, replacing the reeds they had been using up until then. Feathers were stripped, buried in hot sand to harden, hollowed out and then filled with ink. They were time-consuming to make and had to be refilled and reshaped regularly, but continued to be the main writing implement until the metal pen became popular in the mid-19th century.

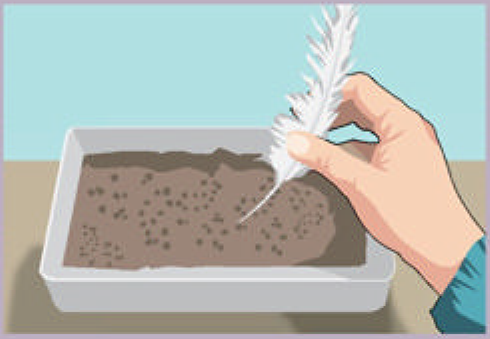
How to make a quill

Travel back through time to the Middle Ages and write with feathers



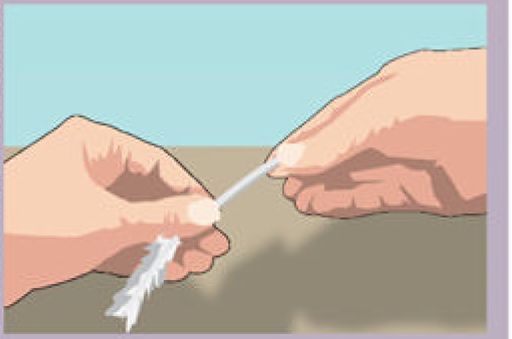
Prime your feather

Scout around near a river or lake for a feather that has been dropped by a swan or goose. Ideally it should be around 15cm (6in) long and intact. Using a Stanley knife, very carefully shave off the fluffy feathers at the pointy end. You should be able to grip the quill without touching any feathers. Then place the feather in a bowl of water and leave it overnight to soak.



Toughen and shape

Heat sand in the oven at 175°C (350°F) and bury the feather, using oven gloves to avoid burns. Wait until the sand has cooled and remove the hardened feather. From about 2.5cm (1in) above the tip, slice down at an angle of around 45 degrees to the tip of the feather. Make a small, flat cut on the opposite side of the tip. There should now be two spikes on the tip that you need to pinch together.



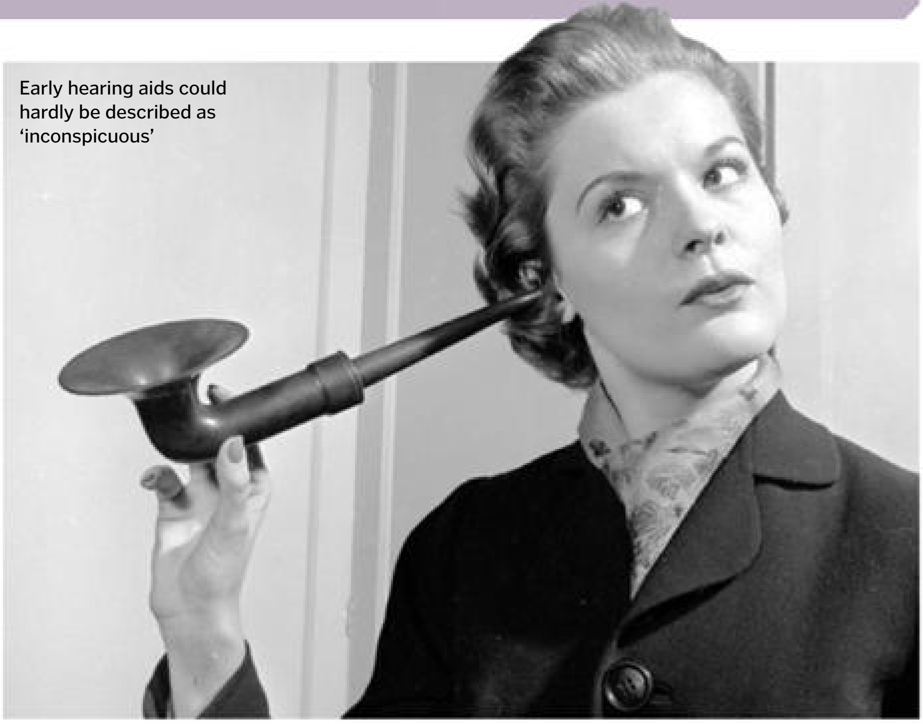
Finishing off

Shave the pinched end so it is nice and smooth and you should have a feather tapering nicely to a point. Dip your quill in the ink where it should soak up the writing fluid. There should be enough to write a fair few lines, depending on how tightly you've pinched it together. The tighter you've pinched it, the more ink it should retain. Take it out and begin writing like a medieval scribe!

The first hearing aids

From 19th-century ear trumpets to microchips

Although they may look like something out of a cartoon, ear trumpets were used frequently throughout the early-19th century. The first type of hearing aid had a large surface area that amplified sound that was directed toward the ear. They were made of metal, silver, wood or animal horns and were incredibly bulky. However, as their use became more widespread, they featured a collapsible design so the ear trumpet could be carried in pockets and removed when necessary. Horns were so popular that even midwives would use a similar instrument to the ear trumpet for listening to pregnant ladies' wombs.

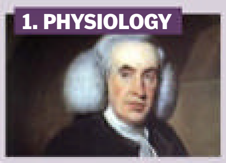


Early hearing aids could hardly be described as 'inconspicuous'

© Thinkstock; Ed Crooks; Getty

HEAD 2 HEAD
18TH-CENTURY MEDICS

1. PHYSIOLOGY



William Cullen

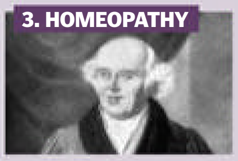
A professor at the Edinburgh Medical School, Cullen's teachings inspired physicians like William Withering, Joseph Black and Benjamin Rush.

2. VACCINATIONS

Edward Jenner

Jenner was the first to understand vaccination and proved that an injection of mild cowpox would make you immune to more deadly smallpox.

3. HOMEOPATHY



Samuel Hahnemann

The original founder of homeopathy, he was one of the first to describe the use of highly diluted drugs to allow the body to heal itself.

DID YOU KNOW? *The term 'apothecary' originates from the Latin 'apotheca', which is where spices and herbs were stored*

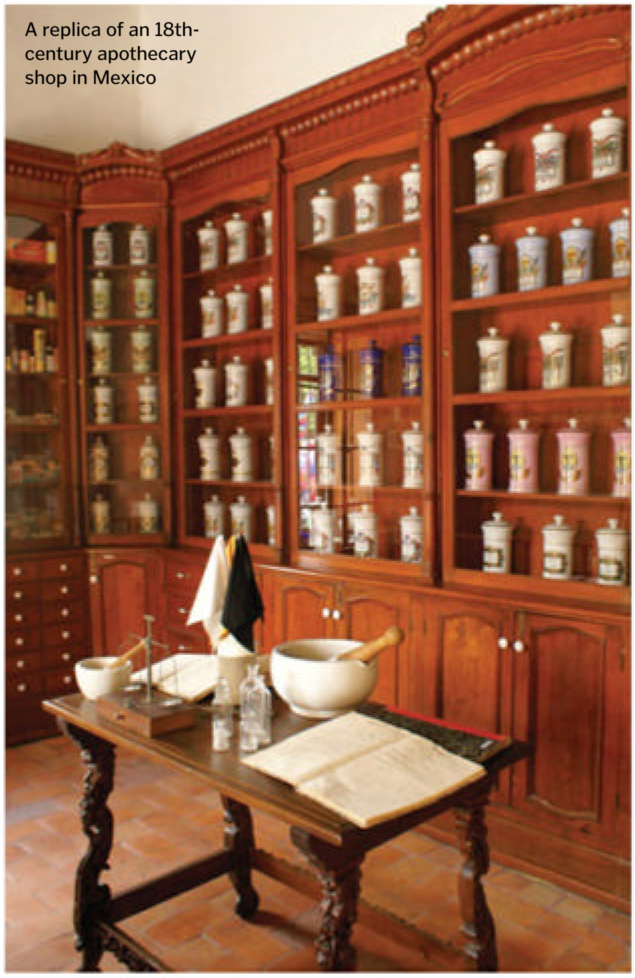
Apothecary secrets

What are the origins of the pharmaceutical industry?

It's thought the first apothecary – which can mean both pharmacy or pharmacist – emerged in Ancient Babylon and was introduced to the West by Galen, a Roman doctor. It originally revolved around the preservation of food, but its focus shifted to the relationship of drugs and medicines with living systems and the process of recording symptoms for the cure and prevention of disease.

The preparation and selling of medicines was handled by an apothecary after the Society of Apothecaries was established in London in 1617. By the 19th century, their role had evolved. The Apothecaries Act in 1815 meant that chemists now had to have formal qualifications and provide medical care and surgery, while new chemist shops would look after the retail side. The practice evolved into pharmacology as new substances were developed such as morphine, strychnine, atropine and quinine. Morphine, for example, was isolated in 1805 by Friedrich Setürner who stirred and heated opium in methanol.

Apothecaries remained prominent throughout the 20th century, with about 100 apothecaries still in the USA during the 1960s. The age of apothecaries all but came to an end in the 1980s as large chain drug stores superseded them.



A replica of an 18th-century apothecary shop in Mexico

Apothecary treatments

1 Artificial leech

Rather than using real leeches for bloodletting, a man-made alternative was created by Carl Baunscheidt in the mid-19th century. It was a pen-like device with a group of tiny needles on the end.

2 Vesiculation

Used to combat madness and hypochondria, this involved intentionally raising blisters on the skin.

3 Clysters

A medicine injected to help nutrition and cleanse the bowels. Along with vomiting and bloodletting this was seen as a way of 'purging' the body of bad elements.

4 Chamomile

A flower that had sedating and anti-inflammatory effects, it was prescribed for colds and infections and was one of many plants used in medicine.

© Science Museum/SSPL; Alamy

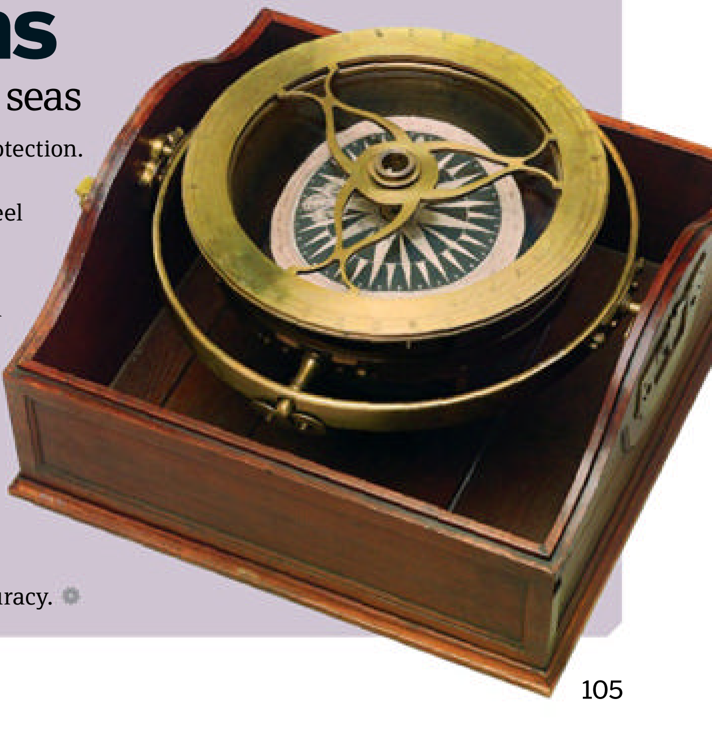
Compass of the oceans

The device mariners once used to navigate the seven seas

The age of discovery owes a lot to the mariner compass. The journeys of pioneering explorers such as Columbus and Vasco de Gama would never have been undertaken if it wasn't for the instrument's ability to help navigate Earth's vast oceans. Like so many instruments of its time, it was originally invented in China. The mariner's compass, or dry compass, was first introduced to Europe around 1300.

Its key components were the gimbal, which allowed the compass to rotate on its axis, a compass card that marked the directions on its face and a lubber line that was used for reference. This was then all held together in a brass frame and wooden box for protection.

Later, in 1745, Dr Gowin Knight designed a needle of magnetised steel that lasted longer and worked with much more precision than the previous version. This was essential to lengthy ocean expeditions, as the needles would not need to be replaced or remagnetised. An upgrade of this system was devised by silversmith Francis Crow in 1813; the new 'liquid compass' had the needle floating on a mix of alcohol and water, again improving on the mechanism's accuracy.



The origins of helicopters

How did we first take to the skies on an aircraft without wings?

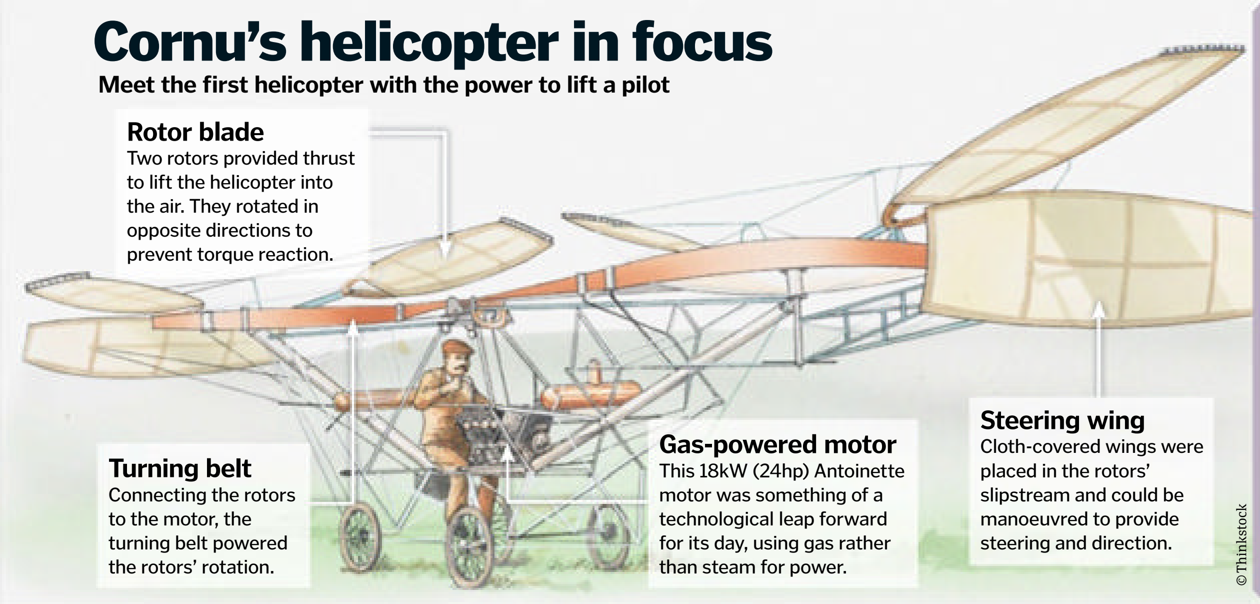
Leonardo da Vinci is the first recorded person to consider the helicopter as a means of transport. He designed an air gyroscope in 1483 with rotating blades and an iron screw to cut through the air.

The late-19th century saw the next big leap forward in helicopter flight, with Englishman Horatio Phillips using a steam engine to power a vertical flying machine. However, Frenchman Paul Cornu used a simple frame, a pair of rotors connected by a belt to a gas-powered motor to lift a person off the ground for the first time.

The Fa-61, built by Heinrich Focke in 1936, was the first to demonstrate controlled flight using a rudder, while Igor Sikorsky pushed this development even further in 1940 with a rotor on the tail to improve steering. Finally, in the 1940s, Sikorsky's R-4 helicopter, now with the ability to move forward at speed and with greater control, became the world's first commercially viable helicopter.

Cornu's helicopter in focus

Meet the first helicopter with the power to lift a pilot



Rotor blade
Two rotors provided thrust to lift the helicopter into the air. They rotated in opposite directions to prevent torque reaction.

Turning belt
Connecting the rotors to the motor, the turning belt powered the rotors' rotation.

Gas-powered motor
This 18kW (24hp) Antoinette motor was something of a technological leap forward for its day, using gas rather than steam for power.

Steering wing
Cloth-covered wings were placed in the rotors' slipstream and could be manoeuvred to provide steering and direction.

© Thinkstock

Helicopter flight physics

A helicopter is an enigma of flight as it doesn't look like it should work. But with careful piloting, they can go places no plane can.

The helicopter motor rotates the blades at high speed. By pressing the collective-pitch lever, the pilot raises the rotor blades to a particular angle. The blades generates lift as they are spun rapidly, with the tail rotor providing sideways force to stop the helicopter spinning out of control as it leaves the ground.

In order to move forward, the rotor blades are angled down at the front. This results in more lift at the back, propelling the chopper forward. Meanwhile, foot pedals are used to control the tail rotor speed, which will direct a helicopter to the left or right.

Pocket watches explained

Find out what's going on inside these portable timekeepers…

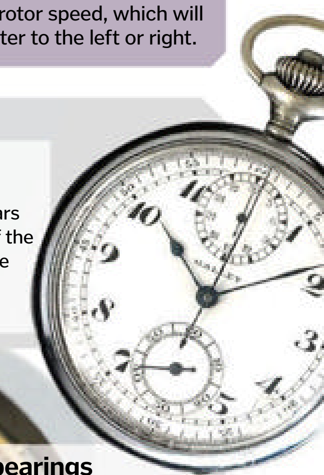
German watchmaker Peter Henlein is considered the father of pocket watches. His spring-based design involves winding up a watch and compressing a coiled spring. The coil's steady expansion provides the energy for the gears to turn, pushing the hand around via a wheel. The first pocket watches only had an hour hand but, as time went by, minute and second hands were added, operated by interlocking gears.

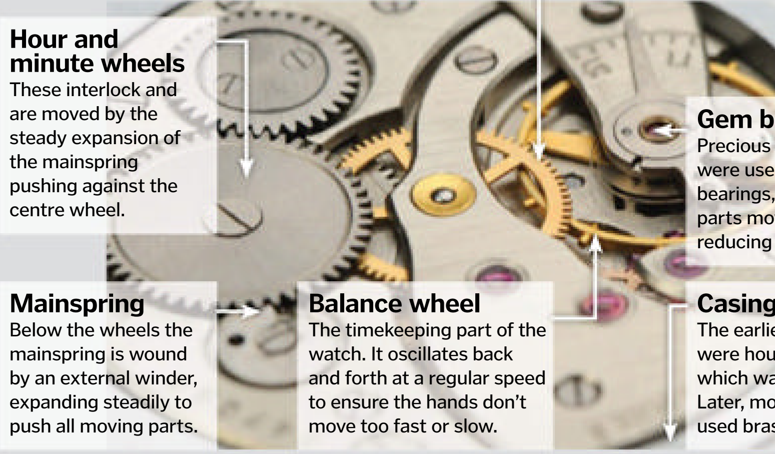
Initially, pocket watches had to be wound twice a day, as the hour hand completed two full rotations, but as more hands were added, watches only needed winding once a day.

Henlein's design was so successful that the mainspring design is still being used today, despite being over 500 years old.

Inside a pocket watch

What makes these mini timepieces tick?





Centre wheel
This is the piece upon which all the other gears rest. The front pivot of the centre wheel drives the cogs which turn the hands on the face.

Hour and minute wheels
These interlock and are moved by the steady expansion of the mainspring pushing against the centre wheel.

Gem bearings
Precious stones such as rubies were used inside watches as bearings, helping mechanical parts move more smoothly, reducing wear and tear.

Mainspring
Below the wheels the mainspring is wound by an external winder, expanding steadily to push all moving parts.

Balance wheel
The timekeeping part of the watch. It oscillates back and forth at a regular speed to ensure the hands don't move too fast or slow.

Casing
The earliest pocket watches were housed in a steel casing, which was strong and cheap. Later, more refined versions used brass, gold and silver.

DID YOU KNOW?

Moving heads

Numerous witnesses have reported heads moving, speaking and blinking for a few seconds after decapitation.

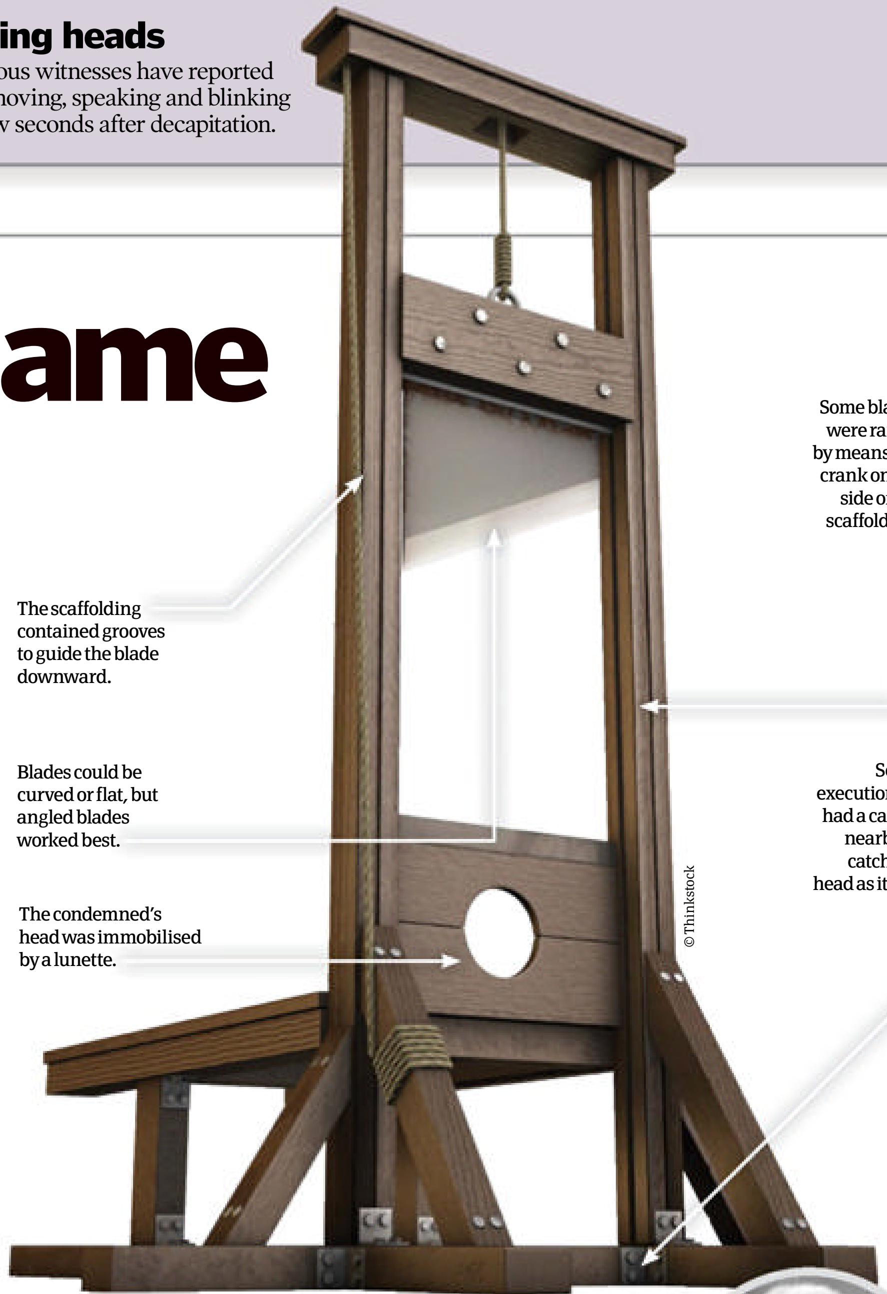
Meet Madame Guillotine

The guillotine was the official method of execution in France until 1981

During the French Revolution, anatomy professor Joseph-Ignace Guillotin proposed that capital punishment in France should be carried out by decapitation on people of all classes because it was the most humane method available. Dr Antoine Louis of the Academy of Surgery designed the machine that came to be known as the guillotine after pointing out that beheading by sword was highly impractical.

The guillotine consists of a wooden frame with an angled blade that runs along grooves. After the executioner raises the weighed blade with a rope, the condemned is placed on a platform with his or her head in a round wooden frame called a lunette. The executioner lets go of the rope, allowing the blade to drop. Until abolishment of the death penalty in 1981, France continued to use the guillotine as its method of execution. Although still legal in a few other countries, the guillotine has not been used since.

> *"Angled blades worked best on the guillotine"*



The scaffolding contained grooves to guide the blade downward.

Blades could be curved or flat, but angled blades worked best.

The condemned's head was immobilised by a lunette.

Some blades were raised by means of a crank on the side of the scaffolding.

Some executioners had a casket nearby to catch the head as it fell.

© Thinkstock

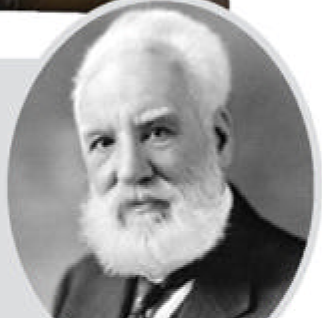
The first telephone

The telephone was a worldwide revolution and the start of instant long-distance communication

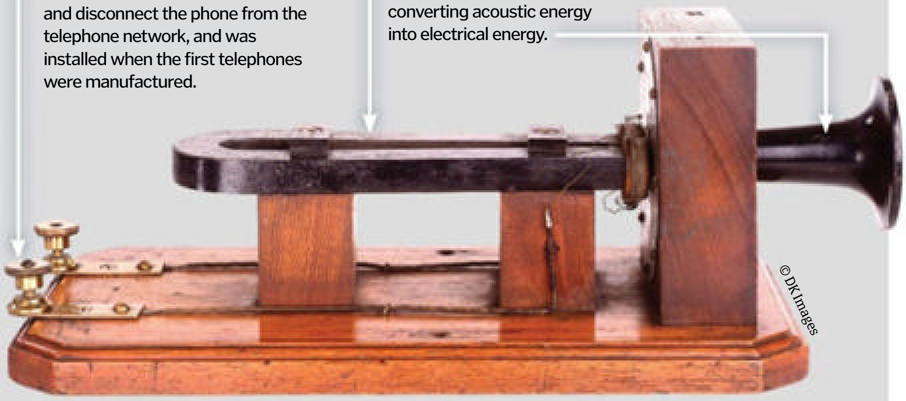
The first telephones to be manufactured featured three main parts: a speaker, a microphone and a hook switch, but the first telephone was much more basic.

Alexander Graham Bell, who is credited with the first patent for the telephone, created an instrument that featured a transmitter formed of a double electromagnet in front of which sat a membrane stretched around a ring holding a piece of iron in its middle. The mouthpiece was positioned before the diaphragm and when sounds were directed upon it, it vibrated and the iron moved.

This movement induced currents in the coils of the magnet which were passed along the electric current of the line to the receiver which consisted of a tubular electromagnet. One end of this was partially closed by a thin circular disk of soft iron and as the current was received the disk vibrated and acoustic sounds were emitted.



Alexander Graham Bell, the father of the telephone



1. Mouthpiece

When a person spoke into the mouthpiece the acoustic vibrations shook the iron held within a stretched membrane in the transmitter which resulted in a variation of voltage, therefore converting acoustic energy into electrical energy.

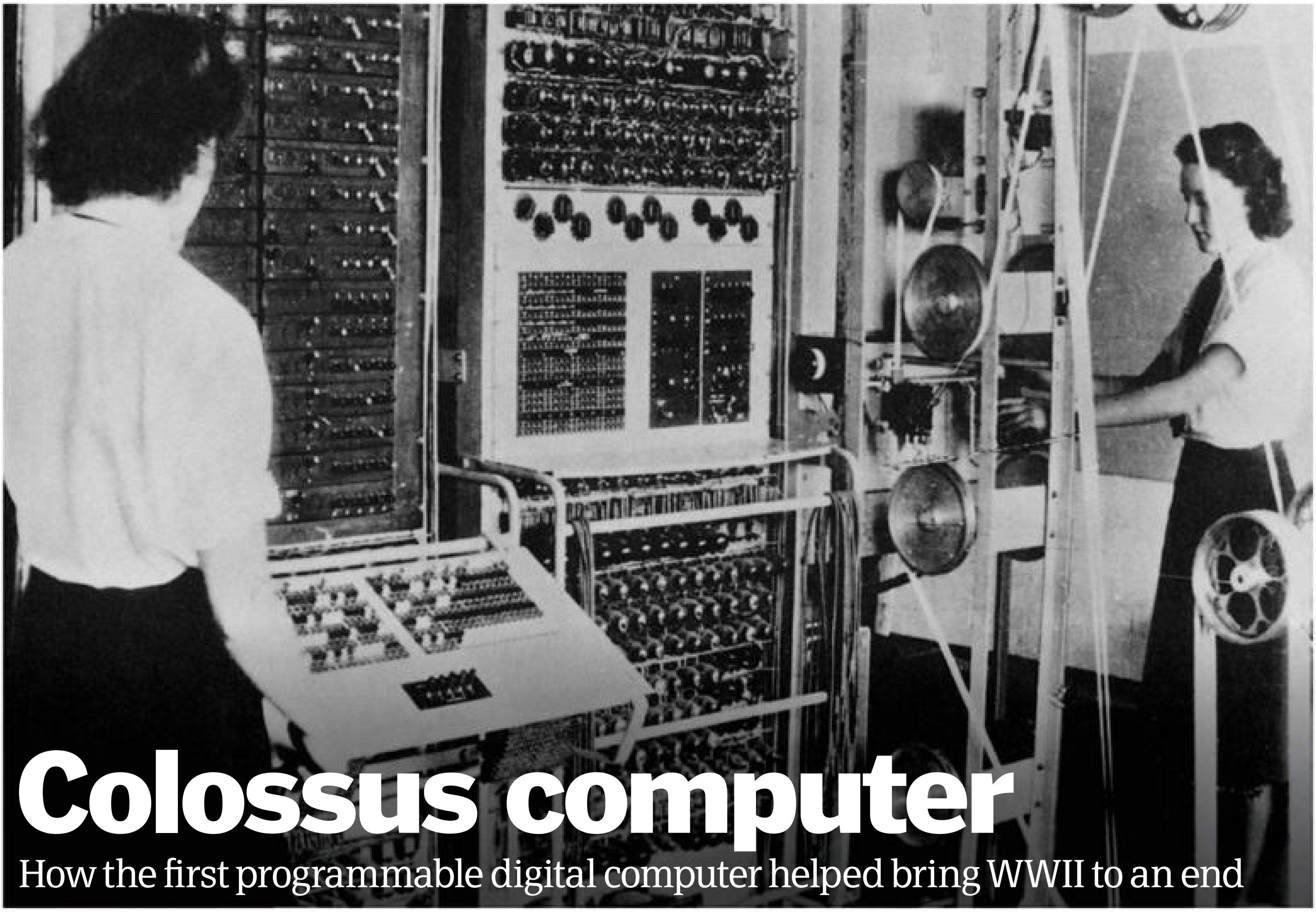
2. Receiver

The electric charges are pulsed through the line and then converted back into acoustic energy at the other end.

3. Hook

A hook switch was later added to the device as was used to connect and disconnect the phone from the telephone network, and was installed when the first telephones were manufactured.

© DK Images



Colossus computer

How the first programmable digital computer helped bring WWII to an end

The Colossus computer was a machine used by the British intelligence service during World War II to analyse and decrypt teleprinter orders and messages enciphered with a Lorenz SZ40/42 encryption machine by the Nazi Germany High Command. The contents of the messages were of incredible value to the Allies, as they often contained key orders for German generals, including troop movements and tactics.

Prior to the German use of the Lorenz cipher, the Allies had successfully cracked their Enigma code and had for years held the ability to decode messages thanks to Alan Turing's electromechanical Bombe machine. The Lorenz cipher was much more complex, however, with the SZ40/42 enciphering a message by combining its characters with a keystream of characters generated by 12 mechanical pinwheels. As such, without knowing the key characters – ie the position of the pinwheels – no decryption could take place.

The Colossus solved this issue by finding the Lorenz key settings, rather than actually decoding the message – the latter part done manually by cryptologists. The computerised process involved the Colossus analysing the inputted encoded message's characters and then counting a statistic based on a programmable logic function (such as whether an individual character is true or false). By analysing a cipher text in this way a number of times, the initial position of the Lorenz machine's 12 pinwheels could be determined and the keystream established.

Historically, the Colossus proved to be a colossal success, with the Allies decoding many war-changing messages throughout 1944 and 1945 and the generated intelligence used to counter the Nazis' movements in Europe. In addition, after the war, the technological advancements in computing brought about by Colossus led to Britain becoming a pioneering centre for computer science.

A colossal reconstruction

As part of the transformation of Bletchley Park into a museum, a fully functional replica of the Mark 2 Colossus was completed in 2007 by a team of engineers led by electrical engineer Tony Sale. Unfortunately, this was nowhere near as simple as six decades' worth of technological advancement since the war might make you think, with many blueprints and original hardware being destroyed after WWII, leaving those responsible for its reconstruction severely lacking in workable information.

Luckily though, after a dedicated research campaign, many of the Bletchley team's original notebooks were acquired, which when collated delivered a surprising amount of information. As such, by using the notebooks and consulting several original members of the Bletchley team, including the designer of the Colossus's optical tape reader – Dr Arnold Lynch – the reconstruction was completed successfully and is today situated in exactly the same position of the original Colossus at Bletchley Park, where it can be used to crack codes once more.

KEY DATES
COMPUTING MILESTONES

1837
Charles Babbage describes his design for the first mechanical computer – the Analytical Engine.

1936
German engineer Konrad Zuse builds the Z1 (right), which is the first programmable computer.

1943
The original Colossus, the world's first programmable electronic digital computer, is built by Tommy Flowers.

1948
The Small-Scale Experimental Machine (right) is built in Manchester. It can store and run a program from memory.

1975
The first machine to be sold to the public as a 'personal computer' is the Altair 8800.

DID YOU KNOW? *The Colossus was not made public knowledge until the 1970s due to the Official Secrets Act*

A sculpture to commemorate Flowers, with his son (left)

Flowers in focus

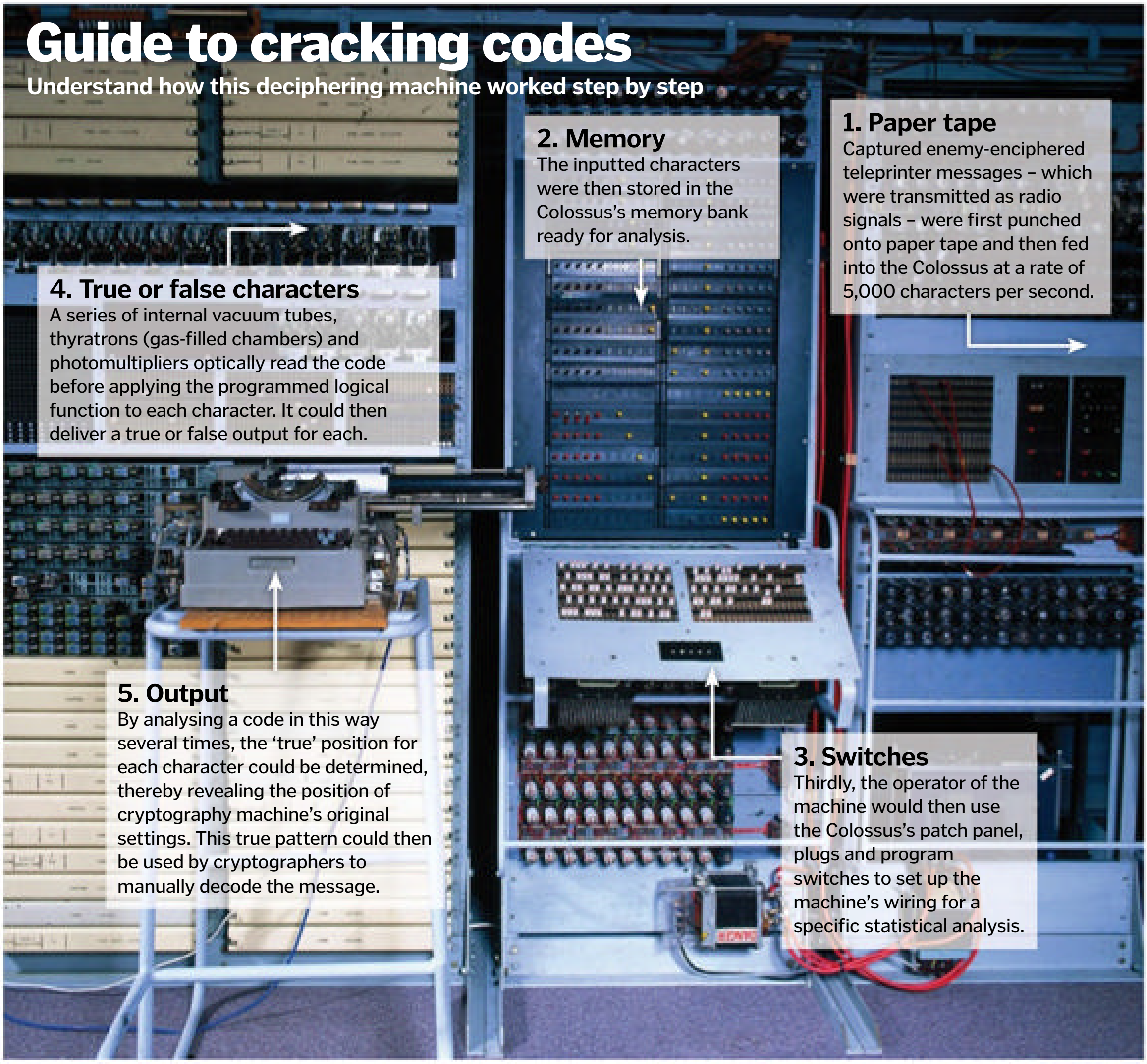
Thomas (Tommy) Flowers was the British engineer behind the design and construction of the Colossus computer. After graduating from the University of London with a degree in electrical engineering, Flowers went on to join the telecommunications branch of the General Post Office, where he explored the use of electronics for telephone exchanges.

Off the back of this work, Flowers was invited to help code-breaking expert Alan Turing to build a machine that could help automate part of the cryptanalysis of Nazi Germany's Lorenz cipher – a high-level cipher used to communicate important orders from the high command.

By 1943 Flowers had built the Colossus, and soon after received funding to create a second improved variant, which went into active service in June 1944. Despite his key role in helping the Allies to victory, Flowers could not talk about his work for decades as he was sworn to secrecy.

Guide to cracking codes

Understand how this deciphering machine worked step by step



1. Paper tape
Captured enemy-enciphered teleprinter messages – which were transmitted as radio signals – were first punched onto paper tape and then fed into the Colossus at a rate of 5,000 characters per second.

2. Memory
The inputted characters were then stored in the Colossus's memory bank ready for analysis.

3. Switches
Thirdly, the operator of the machine would then use the Colossus's patch panel, plugs and program switches to set up the machine's wiring for a specific statistical analysis.

4. True or false characters
A series of internal vacuum tubes, thyratrons (gas-filled chambers) and photomultipliers optically read the code before applying the programmed logical function to each character. It could then deliver a true or false output for each.

5. Output
By analysing a code in this way several times, the 'true' position for each character could be determined, thereby revealing the position of cryptography machine's original settings. This true pattern could then be used by cryptographers to manually decode the message.

In 1993 Bletchley Park was re-opened as a museum devoted to code breakers

Bletchley's role in WWII

Bletchley Park was the British government's main decryption headquarters throughout World War II. Located in Milton Keynes, Buckinghamshire, England, Bletchley was a top-secret facility for Allied communications, with a diverse team of engineers, electricians and mathematicians working manually – and later with the help of decryption machines – to break the various enemy codes used to disguise orders and private communiqués.

Among the many decoders – also known as cryptanalysts – working at Bletchley, Alan Turing became by far the most famous, with his work in breaking the Enigma and then Lorenz codes earning him the nickname the 'Father of Computer Science'. Indeed, between them Turing, Flowers and the rest of the Bletchley team's efforts arguably were crucial to the Allies' eventual victory in 1945, with the intelligence gathered by them – intel which was code-named 'Ultra' – speculated by some to have shortened the war by up to four years.

Today Bletchley Park is run by the Bletchley Park Trust, which maintains the estate as a museum and tourist attraction, with thousands of people visiting the site every year. Among the Trust's many activities is the reconstruction of many of the machines that helped to break the Axis codes – as discussed in more detail in 'A colossal reconstruction' opposite.

After WWII Alan Turing went on to advance our knowledge of computers and artificial intelligence even further

© Getty; Alamy; BT

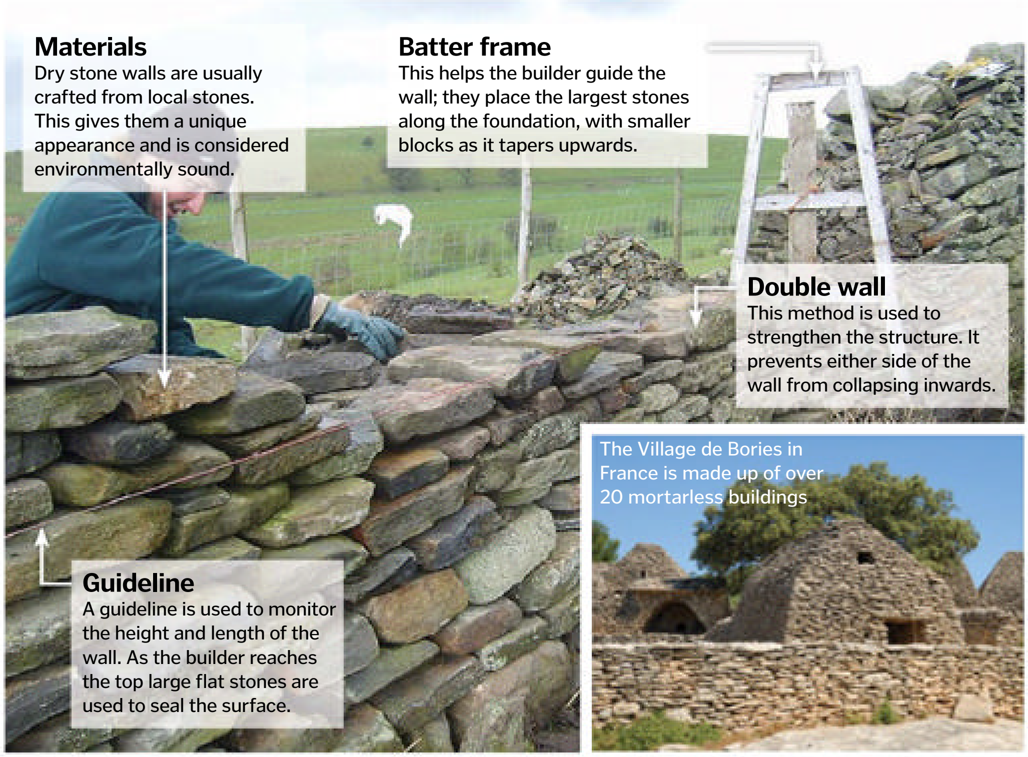
How dry stone walls are built

This clever form of masonry dates back centuries and has been used to make all manner of structures without any cement, relying instead on craftsmanship and gravity

Dry stone walls form the architectural backbone of history. They are comprised of a series of interlocking stones carefully stacked and balanced together without the aid of any mortar.

There are various methods adopted during construction, but most are made of regular blocks assembled using wooden frames and measuring lines. Today, dry stone walls are commonly seen in the countryside, where they are used to divide land and crops. However, dry stone walling was also used in the ancient world; indeed, the practice was used in the construction of many prehistoric monuments, Roman bridges and early churches.

On the other hand, its methodology has even been used to create works of modern art. Some of the most famous structures of this kind include the pyramids of Egypt and the cairns of prehistoric Ireland. Perhaps the most elegant use of dry stone walling can be seen at Machu Picchu in Peru, where the Incan civilisation created a magnificent city constructed of polished, dry stone walls.



Materials
Dry stone walls are usually crafted from local stones. This gives them a unique appearance and is considered environmentally sound.

Batter frame
This helps the builder guide the wall; they place the largest stones along the foundation, with smaller blocks as it tapers upwards.

Double wall
This method is used to strengthen the structure. It prevents either side of the wall from collapsing inwards.

Guideline
A guideline is used to monitor the height and length of the wall. As the builder reaches the top large flat stones are used to seal the surface.

The Village de Bories in France is made up of over 20 mortarless buildings

Inside metronomes

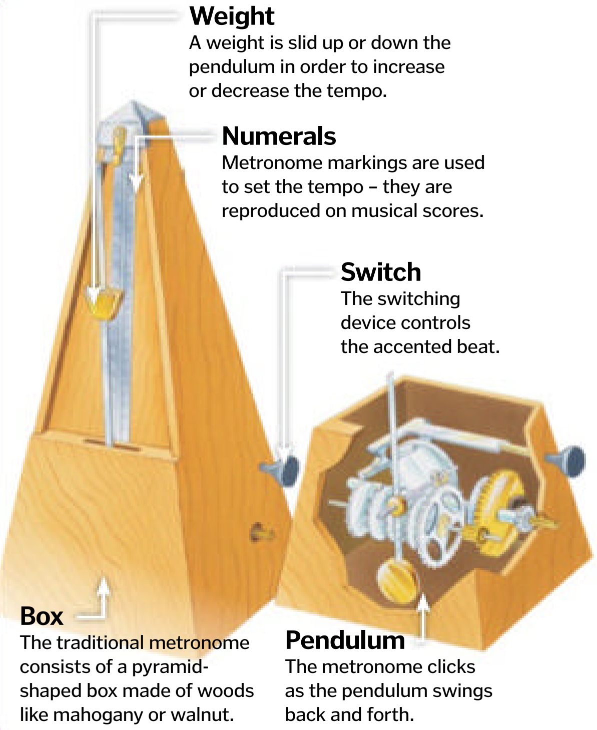
Learn all about these time-keeping instruments that help musicians to keep the beat

The earliest notable scientific experiments with pendulums were conducted by Galileo Galilei in 1602. In 1696, Étienne Loulié adopted his theories and designed the first metronome – an instrument that is still used by musicians today. Received with great enthusiasm, by 1812, Dietrich Nikolaus Winkel was manufacturing 'Maelzel's Metronomes', a device that is still in use.

A metronome produces a systematic series of clicks or beats that can be measured over minutes. Traditional metronomes were designed with a slim pendulum, weighted and attached to a wooden frame; the pendulum counts a series of rhythmic beats.

Today, metronomes are highly advanced and are can be in electronic or digital formats. The beats they produce can help a musician assimilate the timing or 'tempo' of a piece of music. The metronome can be used by composers to mark variances on a written score.

There has been much debate about the use of the metronome. Some musicians believe that it is unnatural for a player to work to an exact tempo. In fact, many notable composers, including Wagner and Brahms, have criticised the metronome, believing that it denies the player a natural form of expression. Those against the tool claim that musicians using one produce a dull 'metronomic' sound.



Weight
A weight is slid up or down the pendulum in order to increase or decrease the tempo.

Numerals
Metronome markings are used to set the tempo – they are reproduced on musical scores.

Switch
The switching device controls the accented beat.

Box
The traditional metronome consists of a pyramid-shaped box made of woods like mahogany or walnut.

Pendulum
The metronome clicks as the pendulum swings back and forth.

© Thinkstock

DID YOU KNOW? *The Central Telegram Office would send 5 million letters by pneumatic tube a year to London's post offices*

What were pneumatic tube systems used for?

Discover how these unusual machines transported messages in a flash

Pneumatic tube systems were a novel form of transportation popular in the late 19th and early 20th century, in which cylindrical containers were transported through a network of metal tubes via compressed air or by partial vacuum.

The systems were developed as an alternative form of courier for objects, letters and even – for a short, experimental time – people, with banks, post offices, telegraph exchanges and offices all connecting themselves via an intra or extranet of tubes.

The most common use for pneumatic tubes was in post offices and telegraph exchanges, with large city-based postal centres connected to local branches by miles upon miles of tubing. These systems greatly sped up the delivery of physical mail, reducing the need for human postal workers to cross large areas of a city, only making the final short connection between local branch and target destination on foot. The same largely became true for banks, with money, deposits and even withdrawals actioned via pneumatic tube.

Indeed, the uptake of pneumatic tube systems was so great that in the latter decades of the 19th century it was even attempted to extend the principle to carry people, with projects such as the 1869 Beach Pneumatic Transit Company in New York building hundreds of metres of subway-style tube networks. While these systems worked, the upscaling in size largely eradicated the efficiency and speed of smaller, post-sized networks, leaving them to be abandoned in favour of traditional rail networks.

Down but not out

Despite pneumatic tube systems garnering widespread popularity and usage through late-19th and early-20th-century cities worldwide, the advent of the digital computer, internet and World Wide Web meant that by the turn of the 21st century, they were almost all redundant. After all, no pneumatic tube system could run a message from London to New York in a matter of seconds like an email can.

However, despite email's dominance, pneumatic tube systems are still used today in select areas – foremost of which is in the medical sphere. Many large hospitals and medical research laboratories have extensive pneumatic tube networks, allowing drugs, tools, blood packs and biological samples to be rapidly transited around typically large and warren-like facilities. To gain a better understanding of how these amazing systems work, be sure to take a look at the video link above.

Telegraph exchange step-by-step

Follow the journey of a telegraph and find out the role pneumatic tubes played

1. Telegraph in
Telegraphs would enter the exchange from their point of origin – ie another post office branch – via manual mail or pneumatic tube delivery.

2. Sorting
The telegraph would be sorted, with its destination logged by human operators.

3. Re-routing
The telegraph would then be re-routed in the exchange, being sent to the relevant dispatch area via an intranet of internal pneumatic tubes.

4. Telegraph out
Once at the dispatch area, the telegraph was sent out by pneumatic tube. This network was extensive in major cities, transporting the telegraph over hundreds of metres.

5. Receipt
The sent telegraph would arrive at its destination's local office or exchange, with the communiqué delivered in person to the recipient.

A secretary collects capsules of documents at a typewriter factory in Hull, UK, in 1954

A tube used to transport airmail between a post office and the airport in the Thirties

© Corbis; Getty

The Parsons steam turbine

How this Victorian generator made steam the driving force behind power production around the world

The steampunk science-fiction sub-genre depicts an alternative reality in which modern devices run on gaseous water. This isn't as far-fetched is it might sound, because roughly 80 per cent of Earth's power stations generate electricity using steam-driven turbines. Appropriately, we have Victorian engineer Sir Charles Parsons to thank for that, as it was his energy and imagination that turned a device dating back to the first century CE into something capable of converting H_2O into power on an industrial scale.

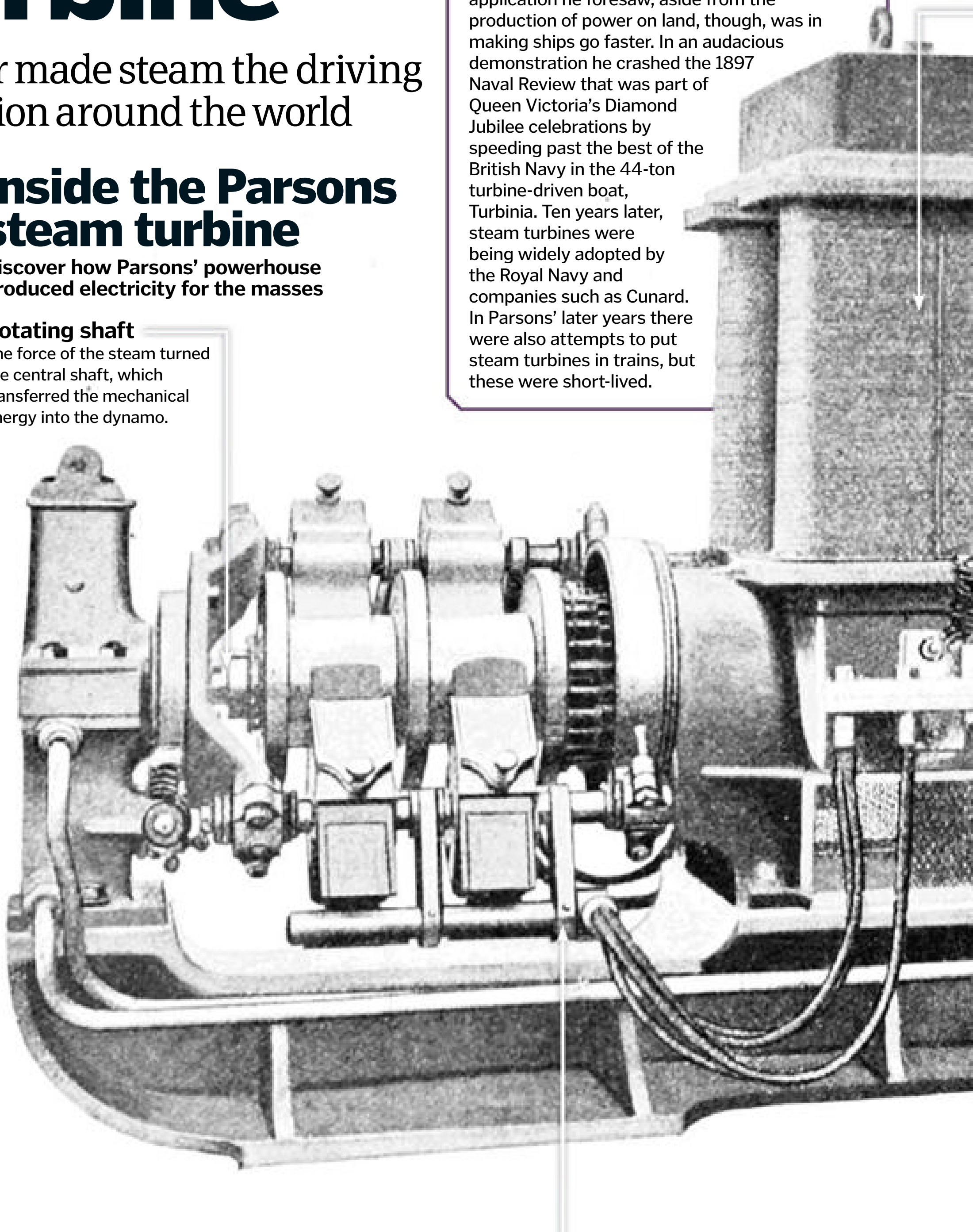
Steam turbines operate on a similar principle to those driven by wind: molecules in a fluid rotate angled blades and produce mechanical energy that can be converted into electrical energy by a dynamo. Instead of meteorological forces providing the thrust, however, it is the impact of pressurised steam emitted from nozzles (impulse turbines) or the change in the pressure of the steam as it expands (reaction turbines).

In Parsons' turbine, water was converted to steam by burning coal. The steam was then literally squeezed into one or more drums containing a series of disc-like rotors attached to a rotating shaft. The perimeter of each rotor was fitted with brass blades designed to receive the force of the steam at high speed without shattering or divert it so that it struck the next set of blades at the proper angle. Successive rotors were fitted with longer blades to expand their diameter and accommodate the increasing volume of the cooling steam.

Parsons' greatest achievements were making the technological advances needed to boost the power output and efficiency of steam turbines. These included inventing a special bearing that allowed the rotors to turn at much faster speeds than had previously been achieved. His basic design is still used today, and because of that the vision of a society dependent on steam is fact, not fiction.

Inside the Parsons steam turbine

Discover how Parsons' powerhouse produced electricity for the masses



Rotating shaft
The force of the steam turned the central shaft, which transferred the mechanical energy into the dynamo.

Dynamo
The mechanical energy generated by the turbine was converted into electrical energy in an attached dynamo.

Steaming ahead

Parsons saw potential in his prime mover in places other than just power stations. He also experimented with turbines as compressors and for driving small-scale machinery such as pumps, fans and blowers. The most significant application he foresaw, aside from the production of power on land, though, was in making ships go faster. In an audacious demonstration he crashed the 1897 Naval Review that was part of Queen Victoria's Diamond Jubilee celebrations by speeding past the best of the British Navy in the 44-ton turbine-driven boat, Turbinia. Ten years later, steam turbines were being widely adopted by the Royal Navy and companies such as Cunard. In Parsons' later years there were also attempts to put steam turbines in trains, but these were short-lived.

RECORD BREAKERS
MEGA-TURBINE

1.8GW

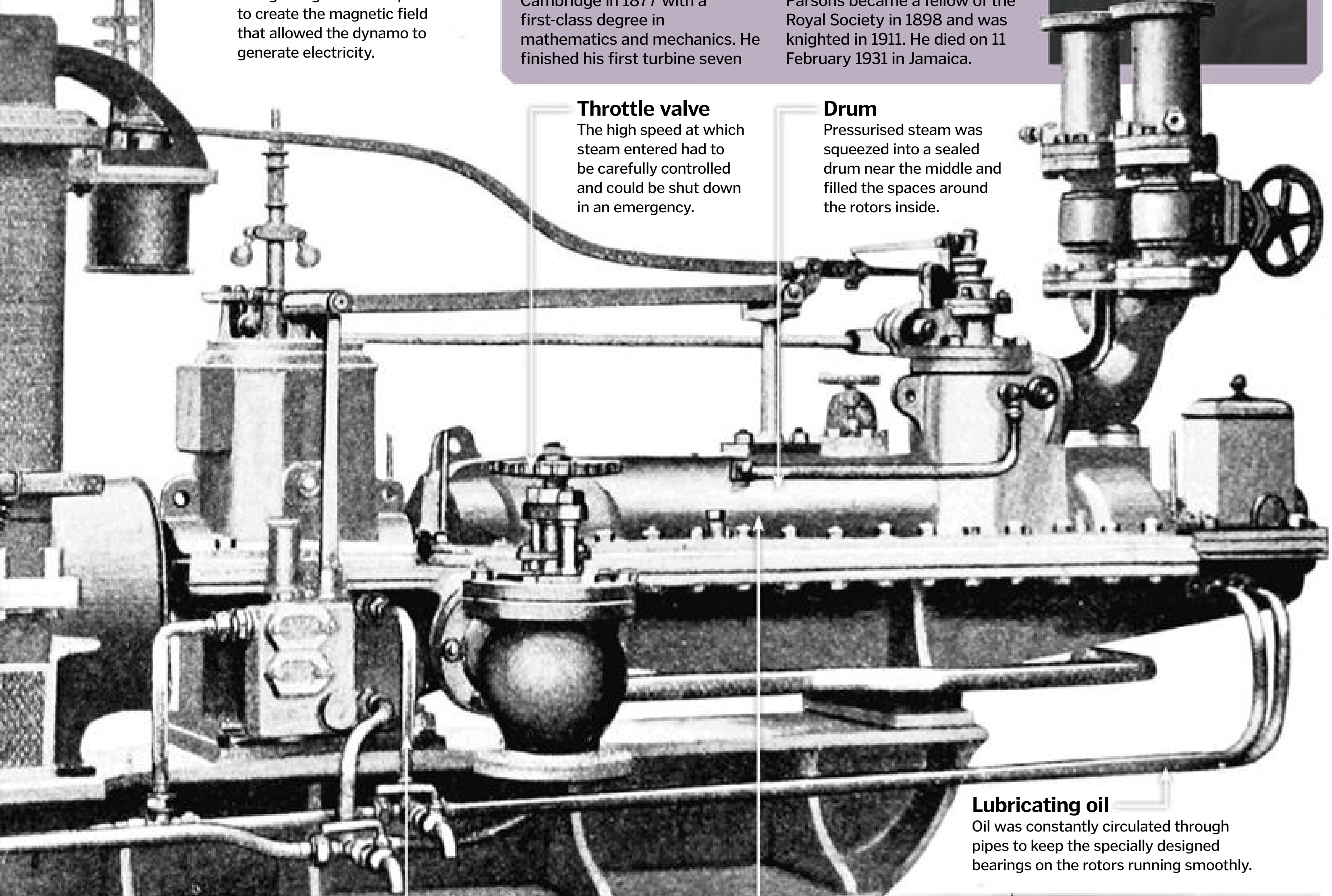
LARGEST NUCLEAR STEAM TURBINE

Named Arabelle, this mega-generator made by Alstom yields over 30 times as much electricity as Parsons' top turbine, and is fitted with 1.9-metre (6.3-foot) rotor blades – the longest in commercial use.

DID YOU KNOW? *Parsons also invented the auxetophone, which amplified sound by passing compressed air through a valve*

Who was Sir Charles Parsons?

Charles Algernon Parsons was born in London on 13 June 1854. He was the youngest son of Irish astronomer William Parsons, the Third Earl of Rosse, who served as president of the Royal Society. Parsons graduated from Cambridge in 1877 with a first-class degree in mathematics and mechanics. He finished his first turbine seven years later and subsequently founded companies to develop his turbo-generator designs. He would go on to set up the Marine Steam Turbine Company, which built turbines for battleships such as the HMS Dreadnought. Parsons became a fellow of the Royal Society in 1898 and was knighted in 1911. He died on 11 February 1931 in Jamaica.



Magnet
A large magnet was required to create the magnetic field that allowed the dynamo to generate electricity.

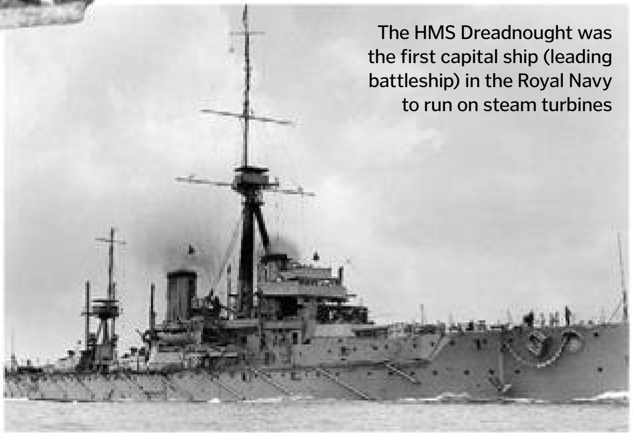
Throttle valve
The high speed at which steam entered had to be carefully controlled and could be shut down in an emergency.

Drum
Pressurised steam was squeezed into a sealed drum near the middle and filled the spaces around the rotors inside.

Lubricating oil
Oil was constantly circulated through pipes to keep the specially designed bearings on the rotors running smoothly.

Guide and moving blades
Inside the drum, the pressurised gas moved across brass blades fitted to the rotors that turned the shaft.

Turbine
Parsons' steam turbine generated mechanical energy by using steam to drive a series of bladed rotors on a rotating shaft.



The HMS Dreadnought was the first capital ship (leading battleship) in the Royal Navy to run on steam turbines

Rack-and-pinion railways

How did these unique transit systems help hefty locomotives scale steeper mountain slopes than ever before?

A rack-and-pinion railway (also known as a cog railway) was one that employed a toothed track. The addition of the toothed rail – which was usually located centrally between the two running rails – enabled locomotives to traverse steep gradients over seven per cent, which remains to this day the maximum limit for standard adhesion-based railways.

Core to the operation of each rack-and-pinion system was the engagement of the locomotive's circular gears onto the linear rack. The rack and pinion therefore was essentially a means of converting the rotational energy generated by the train's powerplant into linear motion on the rack. As both the rack-and-pinion gears had teeth, the system also acted as an additional form of adhesion to the track, with the inter-meshing teeth holding the vehicle in place when not in motion.

Due to the primary form of power traditionally being steam, for rack-and-pinion systems to work the trains needed to be considerably adjusted. This modification stretched from the undercarriage of the train (so pinions could be installed) to the tilting of its boiler, cab and superstructure.

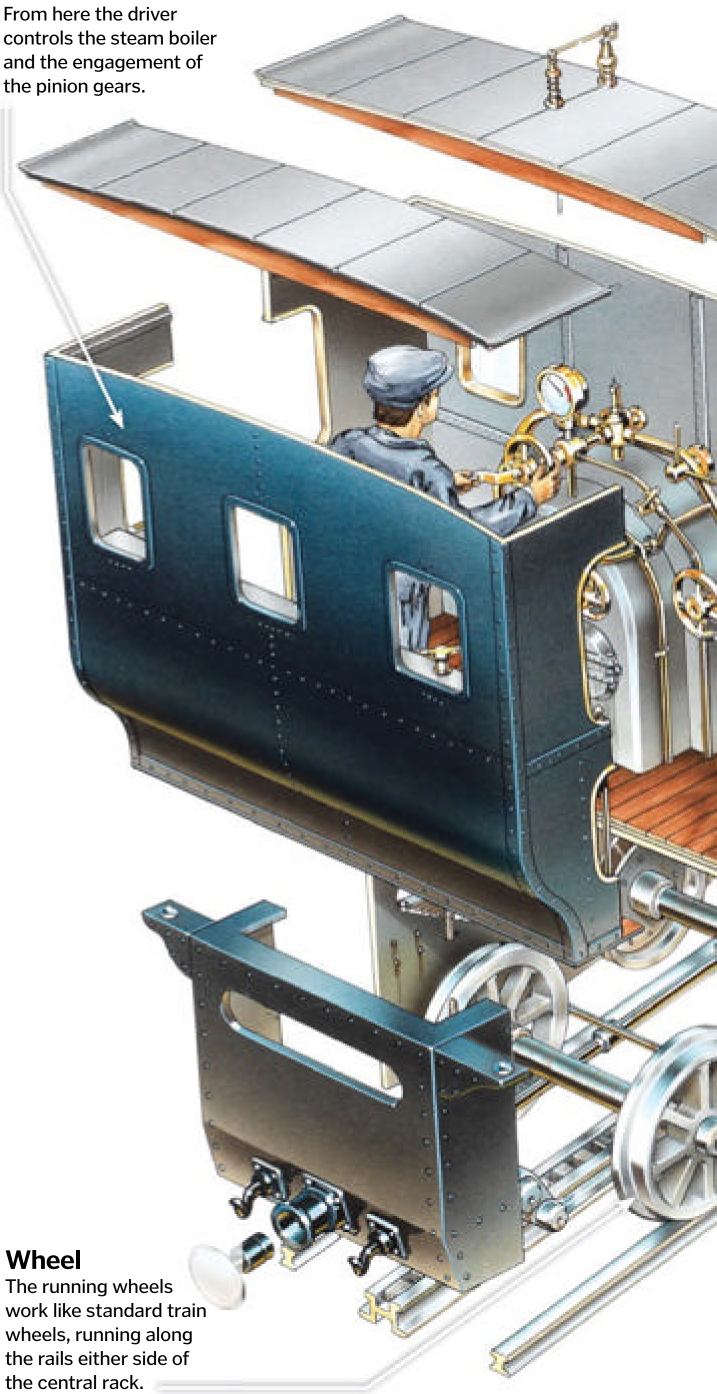
Tilting was necessary as steam engine boilers require water to cover the boiler tubes and firebox at all times to maintain stability – something that is nigh-on impossible to achieve if the train isn't level. As such, cog railway locomotives would lean in towards the track to counter the terrain's gradient.

Today, while rare, rack-and-pinion systems are still in operation worldwide, albeit with a mix of steam engines and diesel/electric locomotives. One of the most famous is the Mount Washington Cog Railway, which we look at more closely in the boxout opposite.

A rack-and-pinion railway built with a Strub system in rural Italy, 1920

Rack and roll

Understand the anatomy of a rack-and-pinion locomotive now with our cutaway illustration



Cabin

To the rear of the engine and carriage is the cabin. From here the driver controls the steam boiler and the engagement of the pinion gears.

Wheel

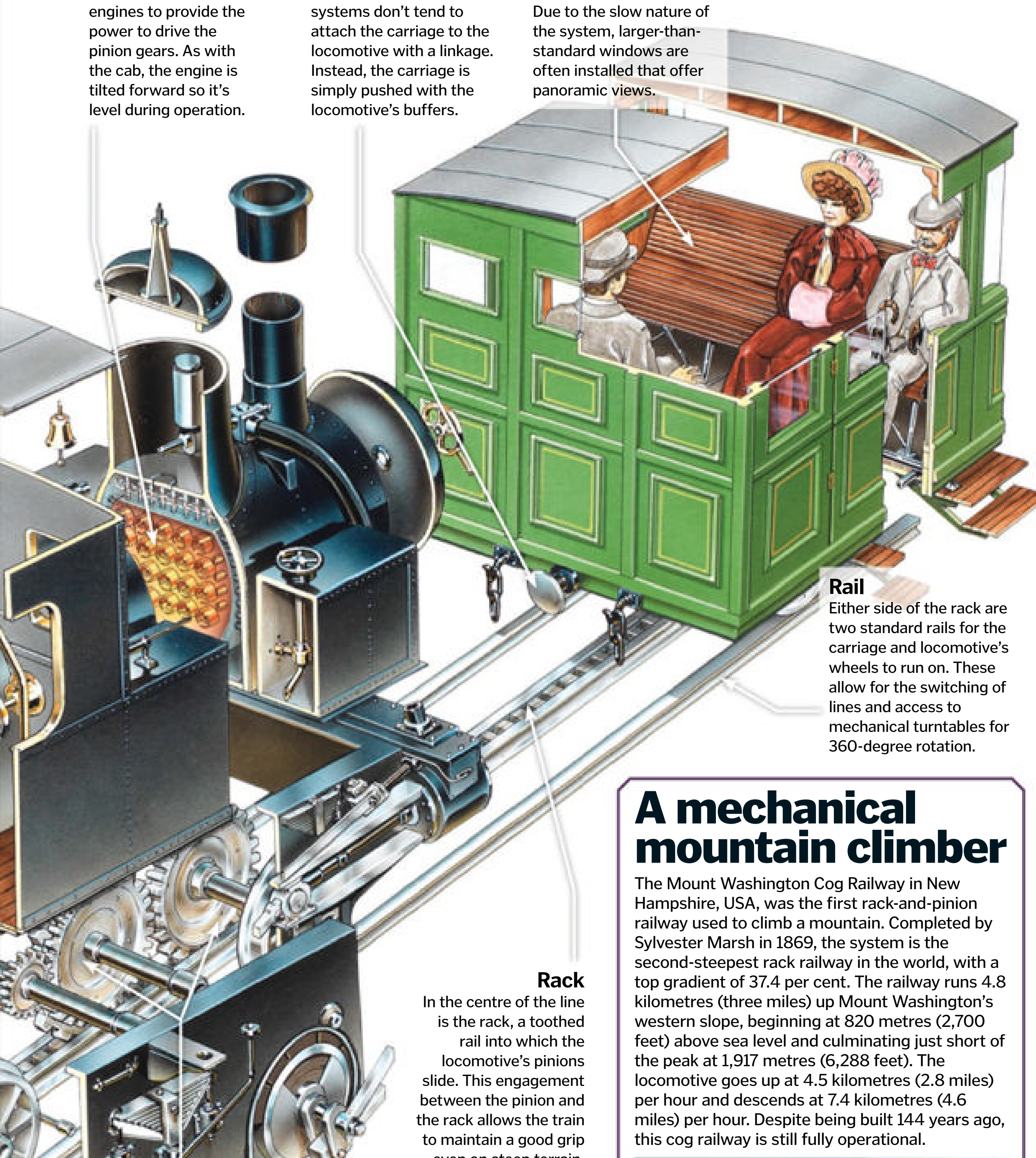
The running wheels work like standard train wheels, running along the rails either side of the central rack.

48%

STEEPEST RAILWAY GRADIENT

This is the maximum gradient of the world's steepest cog railway. The Pilatus Railway runs from Alpnachstad at Lake Lucerne, Switzerland, to a terminus near the Esel summit of Mount Pilatus, climbing 1,635 metres (5,364 feet).

DID YOU KNOW? *The first rack-and-pinion railway was introduced in West Yorkshire, England, in 1812*



Engine
Older cog railways would use steam engines to provide the power to drive the pinion gears. As with the cab, the engine is tilted forward so it's level during operation.

Buffer
Unlike standard adhesion trains, rack-and-pinion systems don't tend to attach the carriage to the locomotive with a linkage. Instead, the carriage is simply pushed with the locomotive's buffers.

Carriage
Passengers sit in a covered wooden carriage. Due to the slow nature of the system, larger-than-standard windows are often installed that offer panoramic views.

Rail
Either side of the rack are two standard rails for the carriage and locomotive's wheels to run on. These allow for the switching of lines and access to mechanical turntables for 360-degree rotation.

Rack
In the centre of the line is the rack, a toothed rail into which the locomotive's pinions slide. This engagement between the pinion and the rack allows the train to maintain a good grip even on steep terrain.

Pinion gears
Mounted to the locomotive's undercarriage is a series of circular, teethed gears. As these rotate, driven by the engine, the teeth slot into the recesses in the rack, helping haul the train along.

A mechanical mountain climber

The Mount Washington Cog Railway in New Hampshire, USA, was the first rack-and-pinion railway used to climb a mountain. Completed by Sylvester Marsh in 1869, the system is the second-steepest rack railway in the world, with a top gradient of 37.4 per cent. The railway runs 4.8 kilometres (three miles) up Mount Washington's western slope, beginning at 820 metres (2,700 feet) above sea level and culminating just short of the peak at 1,917 metres (6,288 feet). The locomotive goes up at 4.5 kilometres (2.8 miles) per hour and descends at 7.4 kilometres (4.6 miles) per hour. Despite being built 144 years ago, this cog railway is still fully operational.

Cog railway evolution

1 Marsh

Made famous by the Mount Washington Cog Railway, the Marsh system – invented by Sylvester Marsh in 1861 – used the locomotive's gear teeth like rollers, arranged in rungs between two 'L'-shaped wrought-iron rails.

2 Riggenbach

The 1863-made system created by inventor Niklaus Riggenbach used a ladder rack made from steel plates connected by regularly spaced rods. While effective, the fixed ladder rack was fairly complicated and expensive to build, so very few examples survive.

3 Abt

Carl Roman Abt improved the Riggenbach system in 1882 by using multiple solid bars with vertical teeth machined into them that were mounted centrally between the rails. This ensured the pinions on the wheels were in constant contact with the rack.

4 Locher

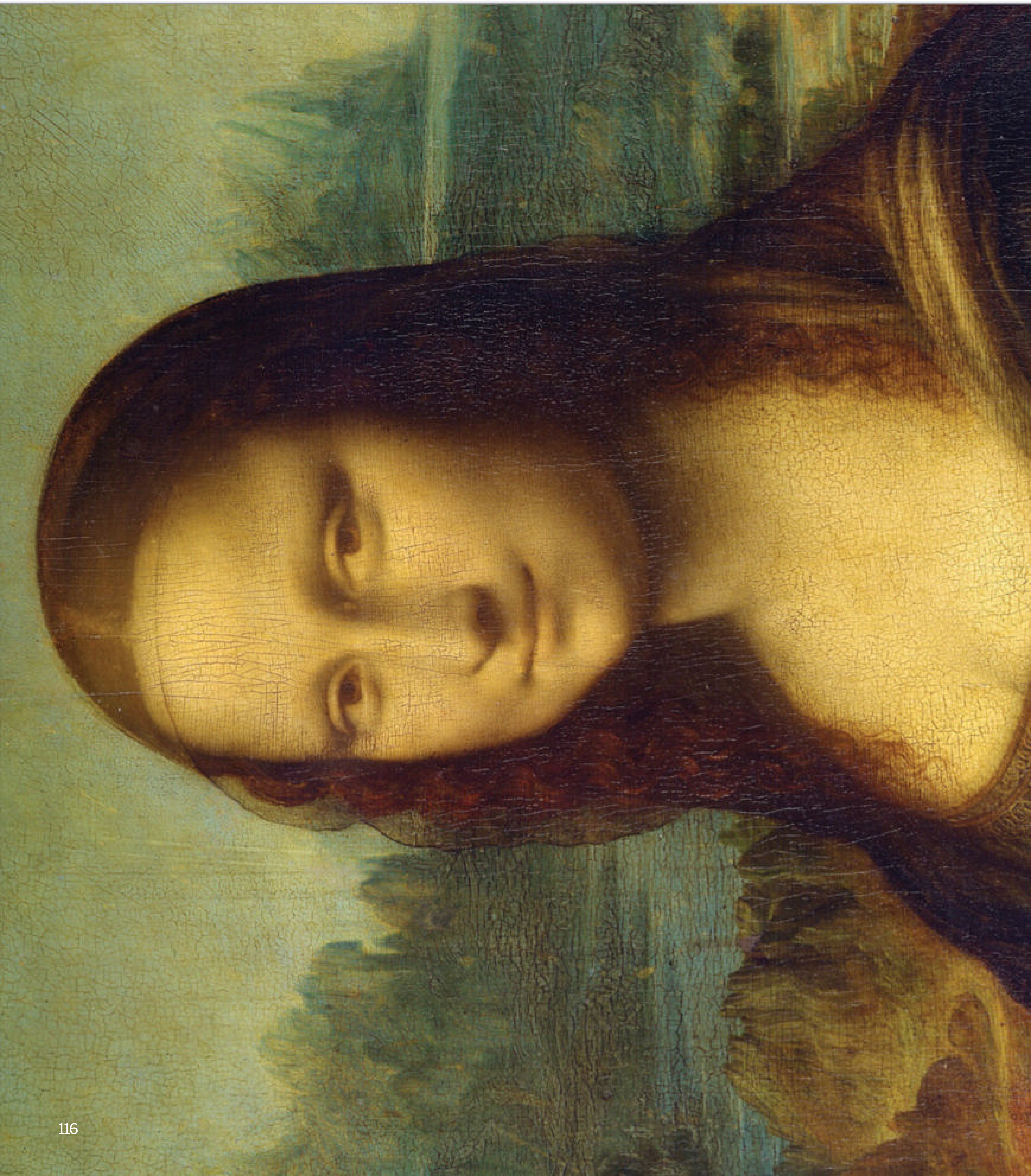
Eduard Locher's 1889 system had gear teeth cut into the sides of the rails rather than the top, which were engaged by two cog wheels on the locomotive. This system could work on steeper track gradients than anything prior.

5 Strub

Invented by Emil Strub in 1896, the Strub system utilised a rolled flat-bottom rail with rack teeth machined into the head 100mm (4in) apart. Safety jaws installed on the locomotive gripped the underside of the head in order to prevent derailments.

© Alamy; Thinkstock

The Mona Lisa



5 TOP FACTS THE MONA LISA

What a steal

1 The *Mona Lisa* was actually stolen from the Louvre museum in Paris on 21 August 1911. However the work of art was later recovered in Italy and returned in 1913.

Bulletproof

2 Today the *Mona Lisa* is displayed behind a bulletproof glass enclosure to prevent damage by vandals, which has been attempted a number of times over the years.

Saving face

3 As the *Mona Lisa* is over 500 years old it has gone through a number of renovation and conservation programmes – the latest seeing it lit by a 20-watt LED lamp.

Popular lady

4 In its current position in the Louvre, the *Mona Lisa* is viewed by over 6 million people per year. As a result it's one of the most viewed paintings on the planet.

Worth millions

5 In 1962 it was assessed at £64.5 million ($100 million). In 2013 it was worth over £489.5 million ($760 million), easily making it the world's most expensive painting.

DID YOU KNOW? *Infrared images of the painting have revealed Da Vinci's original sketch marks beneath the paint/varnish*

Preserving the *Mona Lisa*

What techniques are being used to maintain the world's most well-known painting?

The *Mona Lisa* is an oil painting on a poplar wood panel by Leonardo da Vinci. Believed to be a half-length portrait of Lisa del Giocondo (maiden name Gherardini) – the little-known wife of a Florentine cloth and silk merchant – it's considered the most famous painting on Earth, with millions viewing it every year at the Louvre museum in Paris, France.

As the *Mona Lisa* is over 500 years old, an intensive conservation effort is ongoing to preserve it. This conservation is split into two main areas: frame rectification and painting restoration. The frame is the most altered part of the *Mona Lisa* to date, with the original poplar frame warping to the extent that by the start of the 20th century, a crack had developed. This crack was secured by installing two butterfly-shaped walnut braces into the poplar panel and then later a flexible oak frame and pair of cross braces. Today this physical manipulation is partnered with a closely monitored environment, with the *Mona Lisa* kept in a clear container with controlled humidity, temperature and light levels.

Restoration of the painting itself has gone on for centuries, having first received a wash and new coat of varnish back in 1809. This involved the painting being cleaned with spirits, having specific colours touched up and then being revarnished. Following its theft and return in the early-20th century, the painting was worked on once more, with a number of scratches filled in with watercolour.

Finally, following an attack on the painting by vandals in 1956 which caused damage to the left elbow of the figure, this was also repainted with watercolours. Today, work continues on the *Mona Lisa* to restore much of the colour to the enigmatic portrait, with the wash carried out in 1809 now believed to have removed the top layer of paint. ✿

A special magnifying glass called a loupe is often used to help restore oil paintings

© SPL

The first electric submarine

Learn about the Goubet I – the earliest underwater vessel to be electrically powered

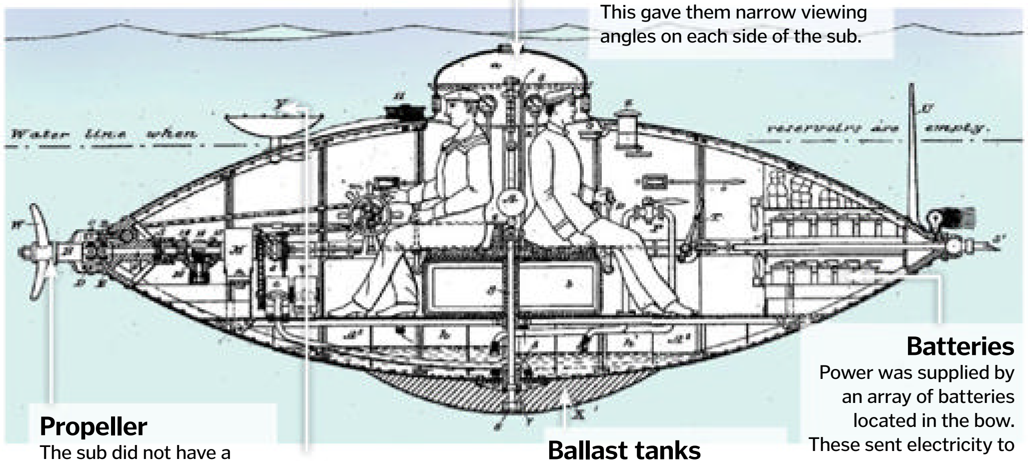
The Goubet I submarine was a two-person, electric submarine built by French inventor Claude Goubet in 1885. Manufactured in Paris, the sub has gone down in history as the first to be electrically powered, with a brace of cutting-edge tech advancing more primitive models.

The Goubet I was battery powered, utilised a Siemens electric motor to drive its propeller and power a navigation light, and measured five metres (16.4 feet) long. The craft weighed in at just over six tons. It was controlled from a central position, with its two crew positioned back to back, seeing out of the vessel via small glass windows; they could see up, down and to the sides to some extent thanks to prisms.

After testing in the River Seine in Paris, however, the Goubet I was ultimately deemed a failure, because the submersible wasn't able to maintain a stable course or depth while moving forward. As a result, while some of its innovative technology lived on in later designs, the Goubet I itself was quickly scrapped.

Tour of the Goubet I

Take a peek inside the first sub that ran on electricity and learn why it failed



Tower
The crew saw out of the Goubet I via a series of windows and prisms in the conning tower. This gave them narrow viewing angles on each side of the sub.

Batteries
Power was supplied by an array of batteries located in the bow. These sent electricity to the pumps and lights.

Propeller
The sub did not have a rudder or dive planes, instead being fitted with a 'Goubet joint' – a mechanism that allowed the propeller to be redirected for steering.

Mine
Quickly commandeered for military ends, the Goubet I could carry a single mine which was released via a wire.

Ballast tanks
Stability was supposed to be ensured by a ballast system that filtered a small quantity of water between the front and back of the vessel, but it didn't work.

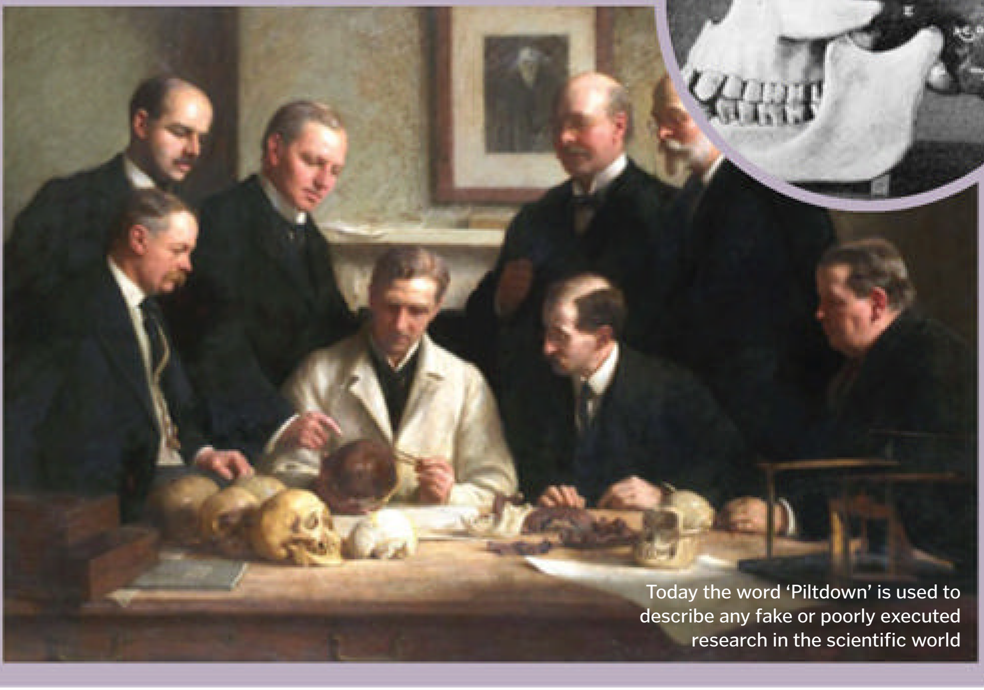
Who was the Piltdown Man?

How did these fake 'missing link' bones fool scientists for decades?

Piltdown Man was a famous hoax in which a species of extinct hominin was supposedly dug up at the Piltdown gravel pit in East Sussex, England, in 1912. The excavation, led by scientist Charles Dawson, appeared to unearth the fossilised fragments of a cranium and jawbone that, on analysis by Dawson and some of his contemporaries, was confirmed as a new species: a missing link between apes and early humans.

For the next 40 years other scientists voiced serious doubts over Piltdown Man's authenticity – especially as later, genuine discoveries left the species isolated in the evolutionary sequence.

These misgivings were eventually proven justified in 1953 after an intensive re-examination of the bone fragments with modern scientific techniques revealed they were in fact from three different species. The cranium was from a modern human, the jawbone from an orangutan and the teeth from a chimpanzee.


Today the word 'Piltdown' is used to describe any fake or poorly executed research in the scientific world

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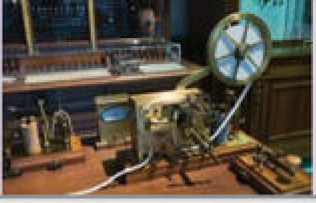
STRANGE BUT TRUE
DISTRESS DECODED

What does the famous message 'SOS' stand for?

A Smelly Old Sausages **B** SOS **C** Save Our Souls



Answer:
It comes as a surprise to many, but the international distress signal doesn't actually stand for anything. The three letters were chosen because they were easy to remember and quick to transmit: 'S' is represented by three dots, while 'O' is three dashes.

DID YOU KNOW? *The facsimile telegraph was invented in the 1930s and was later replaced by the digital fax machine*

Electric telegraph machines explained

How did these early telecommunications devices send and receive messages?

Experienced operators could easily converse at 30 words a minute using Morse code

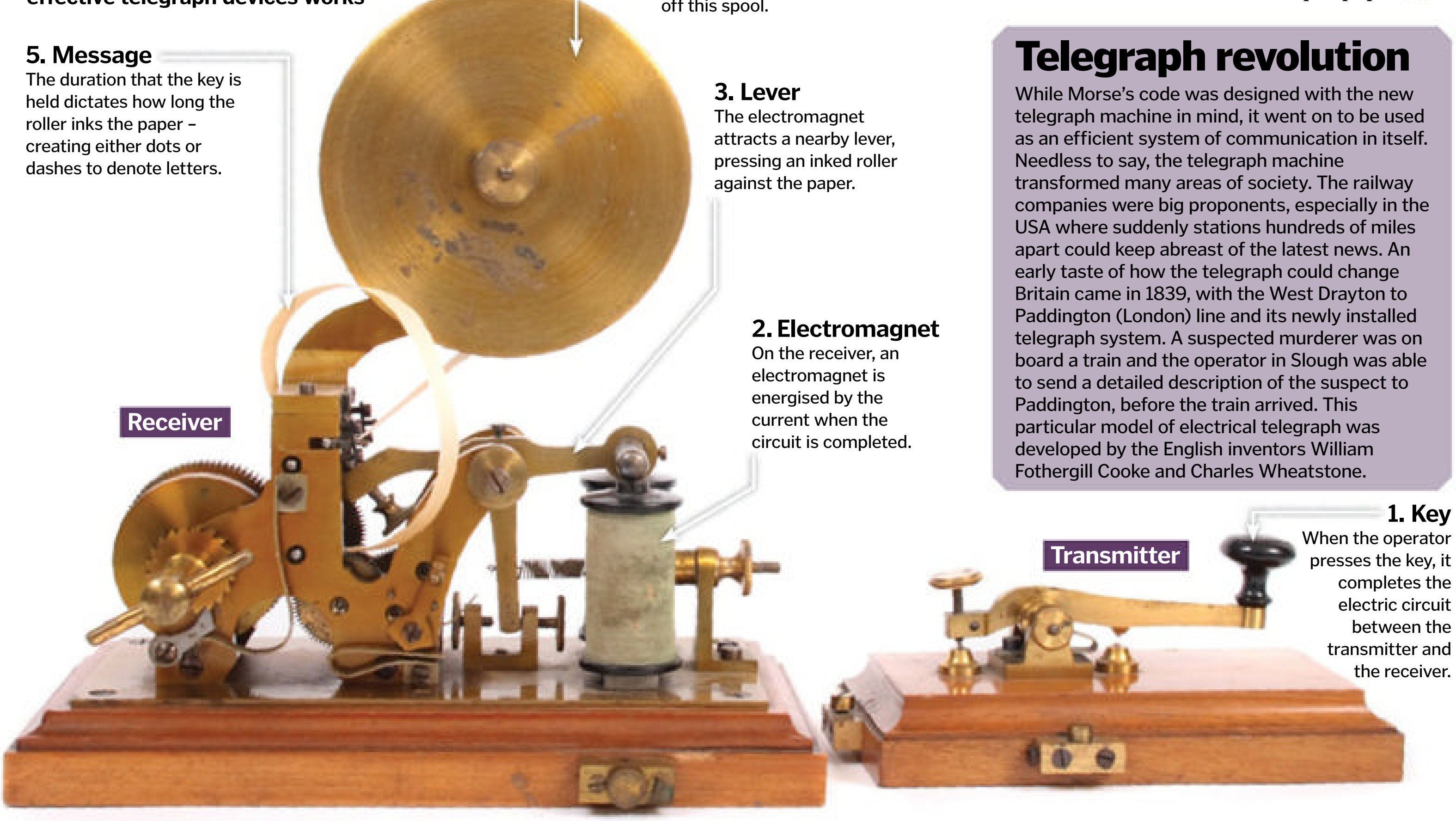
The advent of electricity was the seed that spawned a thousand modern technologies. One of the first to take advantage of this new form of power was the electric telegraph – a machine that could send and receive messages over hundreds of miles of wire in seconds. A number of inventors contributed to the development of this device: Hans Christian Orsted's discovery of magnetic needles deflecting in the presence of an electric current, William Sturgeon's multiturn magnet, and both Michael Faraday and Joseph Henry's advancements of electromagnetism.

One of the most important pioneers of electrical telegraphy was Samuel Morse. Morse was actually a professor of painting and sculpture, but the idea of using electricity to communicate had inspired him. During the mid-1830s – along with his associate, Alfred Vail – he devised a cipher language using dashes, spaces and dots, which is still a part of some naval training to this day: Morse code.

With that established, he went on to invent and patent a telegraph machine in 1837. This was divided into a transmitter and a receiver. The part sending the message – the transmitter – housed a component called a portarule with a moulded typeset, dots and dashes set into it. As the type moved through the mechanism it would intermittently make and break the connection between receiver and battery. At the other end, the receiver would then use a stylus controlled by an electromagnet to print these dots and dashes onto a strip of paper.

Morse code tech

How one of the simplest and most effective telegraph devices works



1. Key
When the operator presses the key, it completes the electric circuit between the transmitter and the receiver.

2. Electromagnet
On the receiver, an electromagnet is energised by the current when the circuit is completed.

3. Lever
The electromagnet attracts a nearby lever, pressing an inked roller against the paper.

4. Spool
A continuous blank strip of paper reels off this spool.

5. Message
The duration that the key is held dictates how long the roller inks the paper – creating either dots or dashes to denote letters.

Telegraph revolution

While Morse's code was designed with the new telegraph machine in mind, it went on to be used as an efficient system of communication in itself. Needless to say, the telegraph machine transformed many areas of society. The railway companies were big proponents, especially in the USA where suddenly stations hundreds of miles apart could keep abreast of the latest news. An early taste of how the telegraph could change Britain came in 1839, with the West Drayton to Paddington (London) line and its newly installed telegraph system. A suspected murderer was on board a train and the operator in Slough was able to send a detailed description of the suspect to Paddington, before the train arrived. This particular model of electrical telegraph was developed by the English inventors William Fothergill Cooke and Charles Wheatstone.

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Darkrooms illuminated

Discover the science and history behind the original photo laboratory

The darkroom was invented around the same time as photography in the early-19th century. Today it's often referred to as the 'Photoshop of the film age' and although they may not be as commonly used nowadays, darkrooms are still popular among traditional film photographers.

The idea of the darkroom came from the camera obscura – a darkened chamber that projected the outside view through a pinhole onto a flat surface like a wall. The concept of the camera obscura dates back to at least the fourth century BCE, but it was not until the 1800s that scientists had any success in capturing the projection as an image using chemicals.

In the early-1830s recording light using silver salts placed on glass plates and eventually paper had been successful. Louis Daguerre's famed process, which dates from around 1833, made it possible to capture stable images using chemicals that would develop the print onto plates. This method – later superseded by William Henry Fox Talbot's calotype process in 1841, which used paper instead of plates – paved the way towards the development of the traditional darkroom we know today.

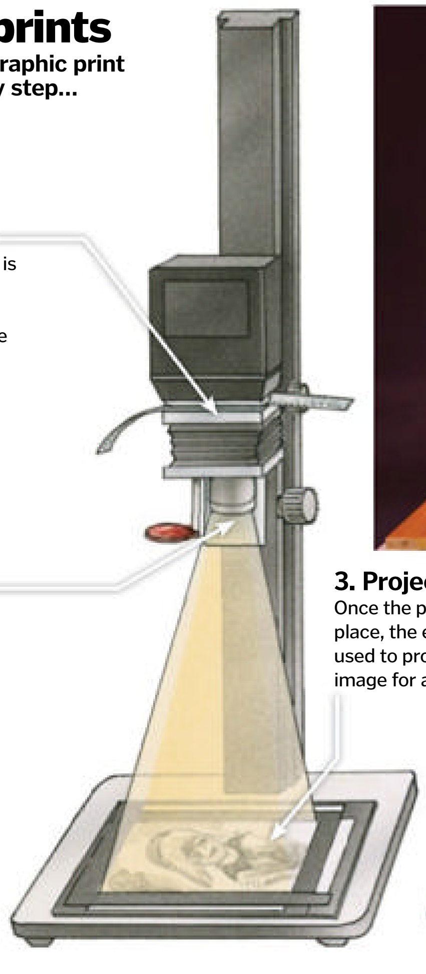
It was not until the invention of black-and-white film in 1885 that darkroom equipment, such as an enlarger, emerged. Working in a darkroom today, you'll find a lot of similar processes to those used over a century ago.

Once film has been developed into a negative using the same chemicals that are required to create prints, you can copy the image onto light-sensitive paper to produce a photograph. To do this, the negative is placed inside the enlarger and projected down. As negatives are reversed, dark areas on the negative will filter the light, which means parts of the paper are less exposed, resulting in highlighted areas in the photograph. Pale areas on a negative, on the other hand, represent the shadows, which means more light is let through to expose and darken the paper. After the light-sensitive paper has been exposed under the enlarger for a set amount of time, it is transferred to a tray of developer solution, where the image will appear. The paper can then be placed in a stop bath to halt the developing process before finally being stabilised with a fixer chemical.

Over the years many photographers have developed darkroom techniques to artistically alter the look of their images. Even today you'll find image-editing software, such as Photoshop, featuring tools mimicking classic techniques – like the Dodge and Burn tools – for bringing a retro look to our digital shots.

Developing prints

How to create a photographic print in the darkroom step by step…



1. Negative
The film negative is positioned inside the enlarger and projected onto the platform below.

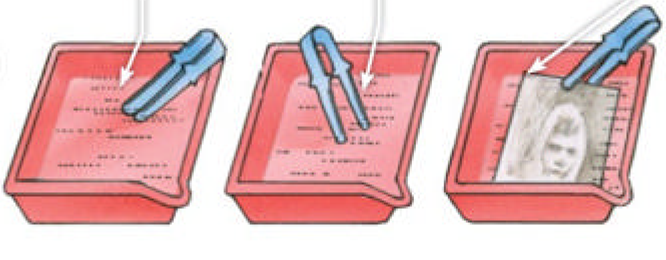
2. Focus/crop
The picture can be focused and cropped before placing the light-sensitive paper down.

3. Projection
Once the paper is in place, the enlarger is used to project the image for a set time.

4. Developer
After the paper has been exposed it will need to lie in a tray of developer fluid to start the process.

5. Stop bath
The paper is then dipped into a stop bath chemical to avoid it over-developing.

6. Fixer
Finally, the paper can be moved into what's known as a fixer, which effectively locks the image in place.



KEY DATES
PHOTOGRAPHY IN DEVELOPMENT

1800
Thomas Wedgwood is the first person to capture permanent images onto paper.

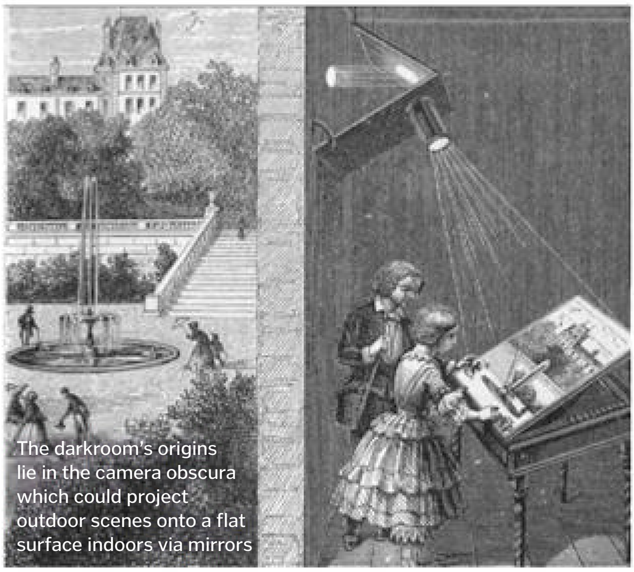
1826
Nicéphore Niépce invents heliography, producing the first snap with a camera obscura.

1833
Louis Daguerre devises his daguerreotype process, using light-sensitive plates and chemicals.

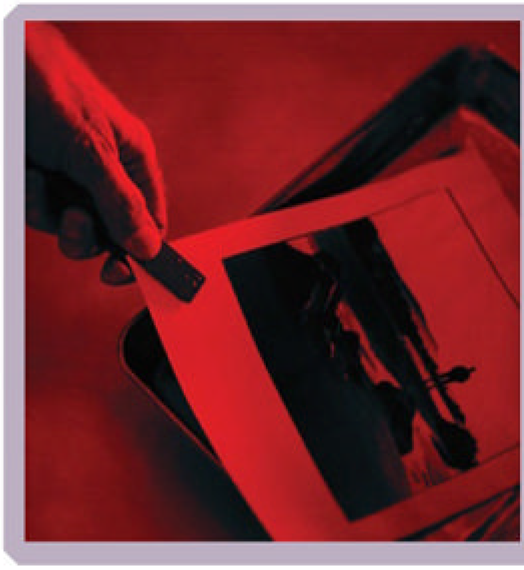
1841
William Henry Fox Talbot improves the photography field with his calotype process.

1885
George Eastman creates paper film and later celluloid film, which will be used in the first consumer cameras.

DID YOU KNOW? *Light-sensitive paper is not affected by red light, hence why it's used in a darkroom to help you see*



The darkroom's origins lie in the camera obscura which could project outdoor scenes onto a flat surface indoors via mirrors



Print chemistry

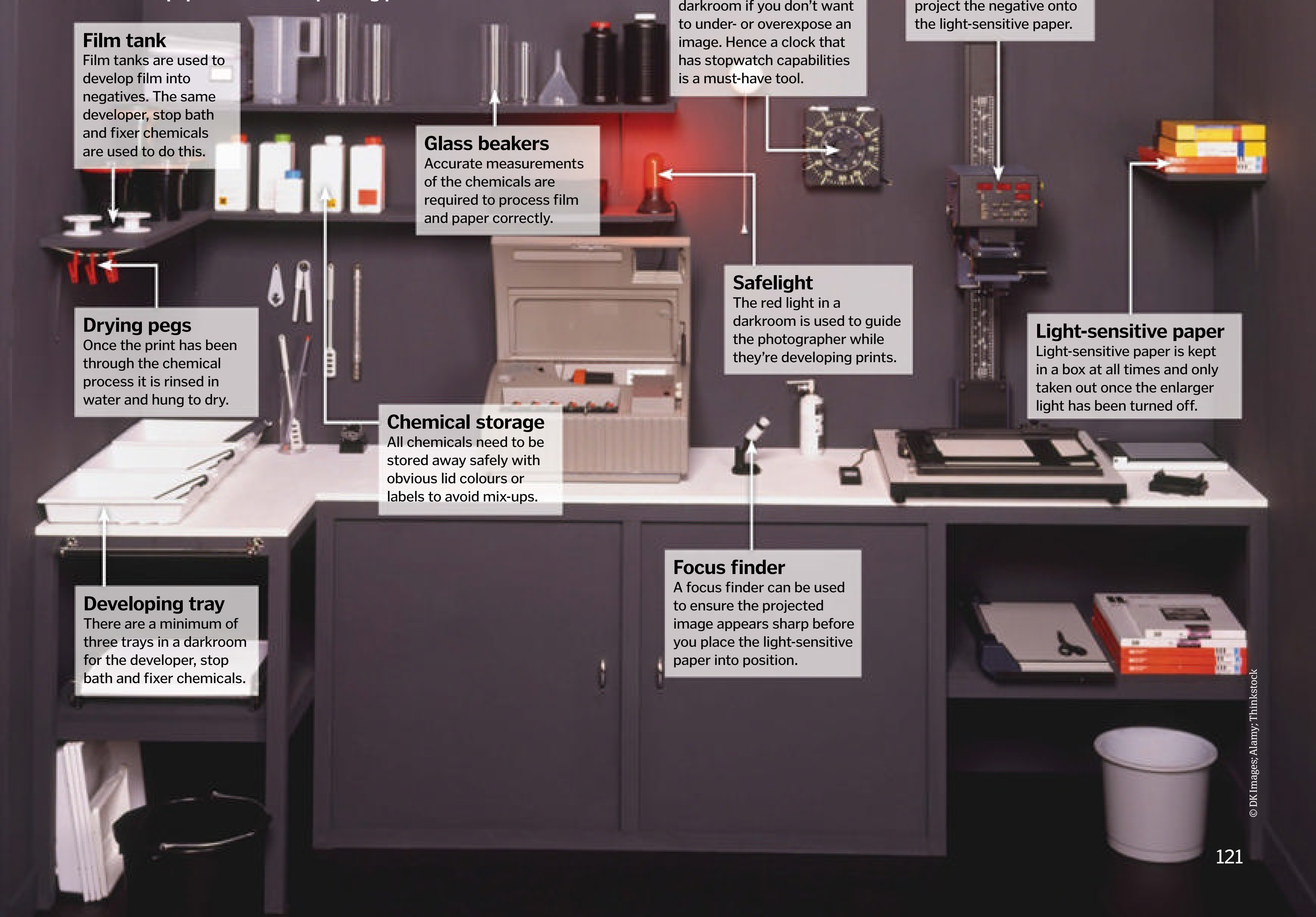
There are three chemicals commonly used to process film and develop photographs onto light-sensitive paper in the darkroom. These include a developer, stop bath and fixer.

The developer is the first stage after exposing the film or paper to light, and is designed to make the latent image visible by reducing the silver halides that have been exposed. A timer is used to prevent the paper from being over-developed and turning black.

The next step is the stop bath chemical which neutralises and halts the developer. The final stage is the fixer chemical, which stabilises the image and essentially fixes it to the paper.

Tour of a darkroom

We shine a light on a darkroom and expose the essential equipment used for printing pictures



Film tank
Film tanks are used to develop film into negatives. The same developer, stop bath and fixer chemicals are used to do this.

Glass beakers
Accurate measurements of the chemicals are required to process film and paper correctly.

Clock
Timing is everything in a darkroom if you don't want to under- or overexpose an image. Hence a clock that has stopwatch capabilities is a must-have tool.

Enlarger
The enlarger is used to project the negative onto the light-sensitive paper.

Drying pegs
Once the print has been through the chemical process it is rinsed in water and hung to dry.

Safelight
The red light in a darkroom is used to guide the photographer while they're developing prints.

Light-sensitive paper
Light-sensitive paper is kept in a box at all times and only taken out once the enlarger light has been turned off.

Chemical storage
All chemicals need to be stored away safely with obvious lid colours or labels to avoid mix-ups.

Focus finder
A focus finder can be used to ensure the projected image appears sharp before you place the light-sensitive paper into position.

Developing tray
There are a minimum of three trays in a darkroom for the developer, stop bath and fixer chemicals.

© DK Images; Alamy; Thinkstock

How do overhead projectors work?

The science behind the classroom classic

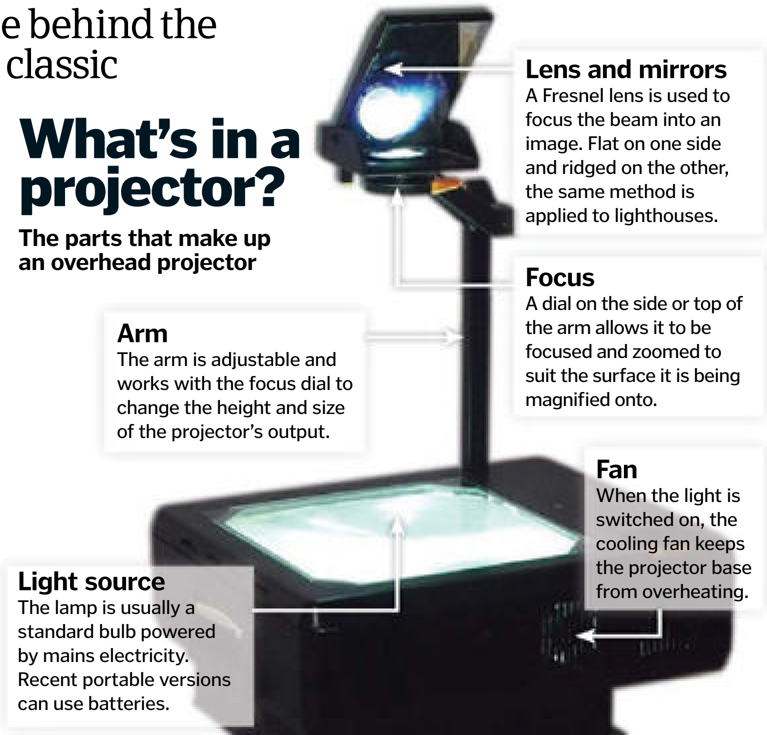
Anyone who went to school in the 1980s and 1990s will remember the overhead projector. Its roots can be traced to a device known as a magic lantern. This was introduced in the 17th century and used candles, lamps or the Sun itself as its light source and an array of mirrors to display painted images.

An overhead projector works by placing a transparency – an A4 sheet of plastic – on top of main projector base. This has a glass top with a lamp underneath, allowing the light to shine through the sheet, reflect off the mirror, out through the lens and onto the surface that it's pointed at.

The projector is a low-cost teaching aid, as the transparencies can be used again and again. Written material can be preprinted onto the plastic sheets and notes can be added in nonpermanent marker, which saves teachers time and resources. However, in recent years the use of the projector has declined due to the rise of computers and LCD projection, as well as presentation programs such as Keynote or Microsoft PowerPoint.

What's in a projector?

The parts that make up an overhead projector



Lens and mirrors
A Fresnel lens is used to focus the beam into an image. Flat on one side and ridged on the other, the same method is applied to lighthouses.

Focus
A dial on the side or top of the arm allows it to be focused and zoomed to suit the surface it is being magnified onto.

Arm
The arm is adjustable and works with the focus dial to change the height and size of the projector's output.

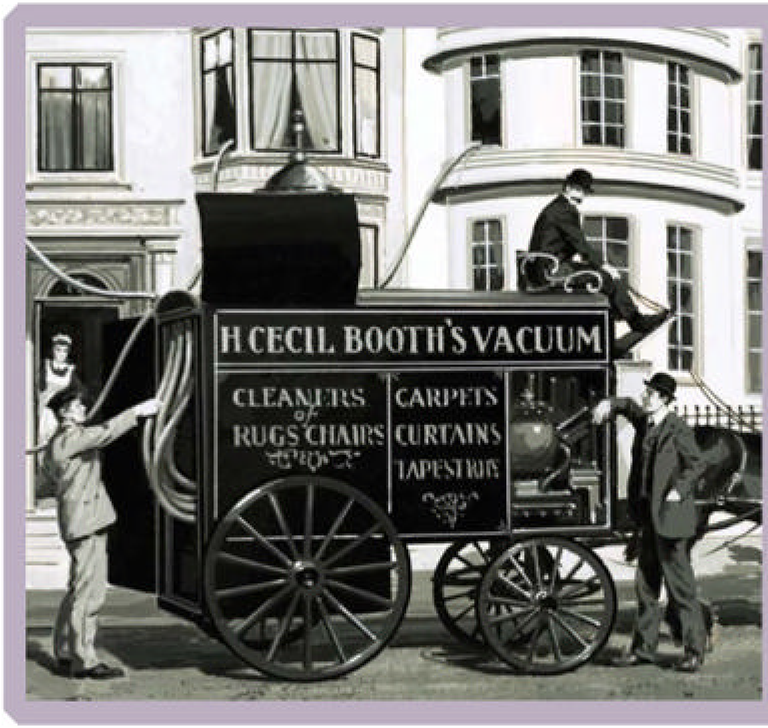
Fan
When the light is switched on, the cooling fan keeps the projector base from overheating.

Light source
The lamp is usually a standard bulb powered by mains electricity. Recent portable versions can use batteries.

Transmissive projectors
Transmissive projectors use an adjustable head and a Fresnel lens to focus the image. These hulks are fast becoming obsolete.

Reflective projectors
The light source is in the head of the projector rather than the base, which shines the light down onto reflective mirrors.

Opaque projectors
Using the same system as the reflective projector, these machines can also display opaque paper and 3D objects.



The first vacuum cleaner

How this horse-drawn vacuum cleaned Victorian houses

British engineer Hubert Cecil Booth patented the motorised vacuum cleaner in 1901. Far from the slender pieces of equipment we have nowadays, this vacuum cleaner was so cumbersome it had to be drawn by a horse and cart. Because most Victorian houses didn't have electricity, Booth's machine had to get its power from coal or oil. It would park outside a house and a 244-metre (800-foot) long hose would snake in through the windows and the oil-powered engine would burst into life. It sucked the dirt into a filter, ridding homes of years and years of accumulated dust. Far too big for everyday use, Booth successfully marketed it as a hired service and was even asked to clean the ceremonial carpet for King Edward VII's coronation in 1902!

© Look and Learn; Dreamstime

How are bronze statues cast?

Explore the complex process behind this centuries-old art

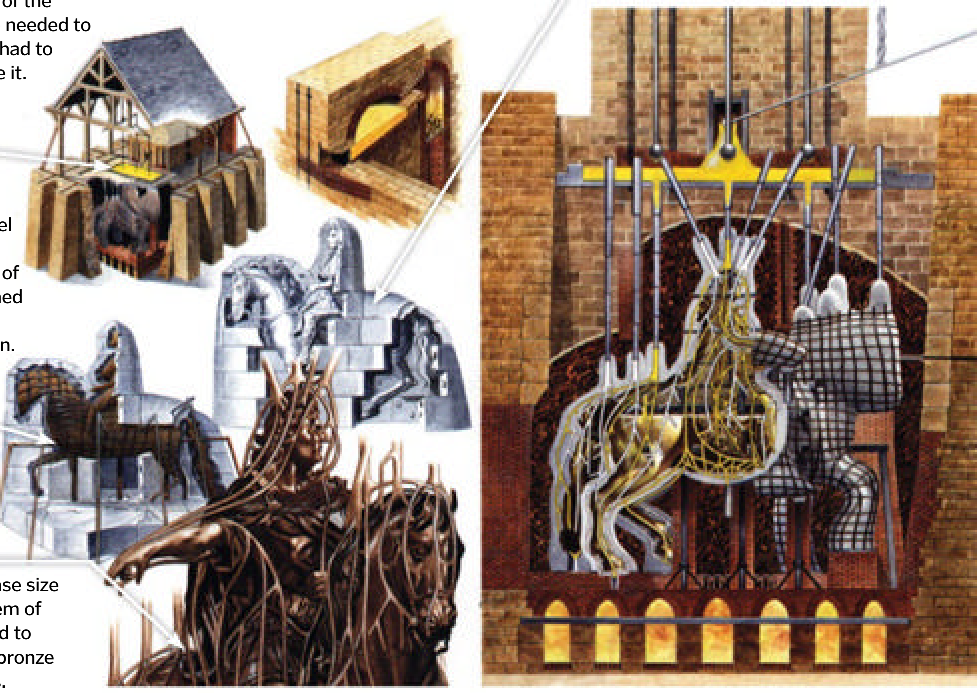
The first step in the casting of a bronze statue is to create a replica of the piece out of wood or clay. Secondly a lubricant such as oil is used to coat the statue followed by a thick layer of silicone rubber. After the rubber has hardened – a process that can take 24 hours – the coating can be removed from the replica, leaving a detailed mould.

Next, the mould is filled with hot wax. After being left to cool, the mould is taken off to leave a wax sculpture. After attaching the wax model to a device called a screw that channels molten bronze via a series of fine channels, the mould is dipped into a ceramic solution and covered with powdered silicon to strengthen it.

The internal wax mould is then melted in a steam oven, while the ceramic one is fired to provide the final mould. Bronze is heated to over 2,000 degrees Celsius (3,630 degrees Fahrenheit) prior to being poured into the mould, solidifying in 30 or so minutes. Lastly the ceramic layer is chipped and sandblasted away to reveal the bronze statue within.

Making Louis XIV on Horseback

See how this famous statue of the French king was created



Stone casing
The replica and castings were protected and structurally reinforced by a thick layer of stone.

Forge
Due to the scale of the model, the forge needed to melt the bronze had to be directly above it.

Model
The replica model for the bronze was created out of wood by renowned French sculptor François Girardon.

Pipework
Due to its immense size an intricate system of pipes was needed to feed the molten bronze into every recess.

What are life-preserving coffins?

How did this odd casket save anyone buried alive?

Very much a historical oddity, the life-preserving coffin was a special burial casket designed by Christian Henry Eisenbrandt in 1843 to allow those mistakenly buried alive to safely get out.

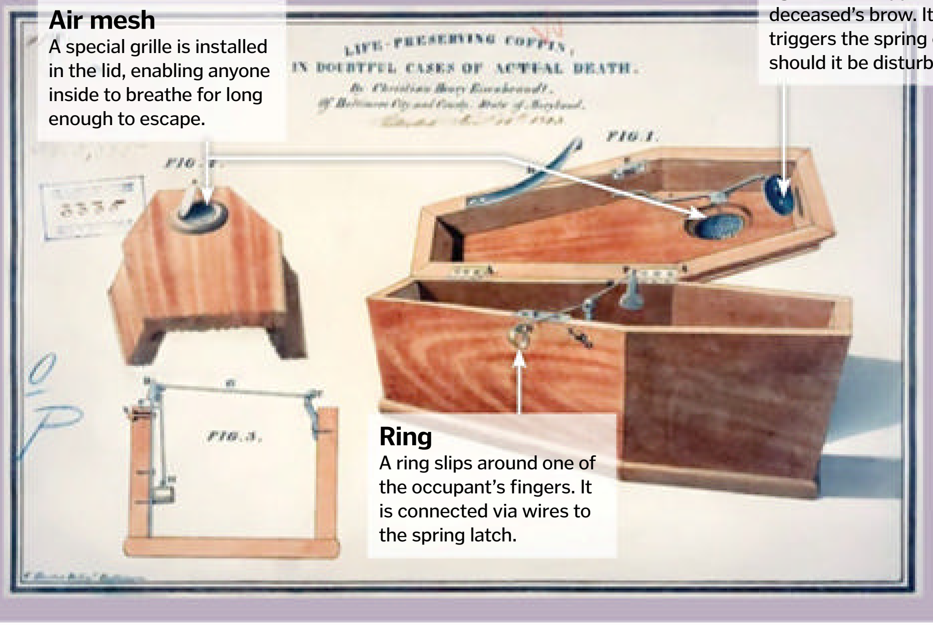
The system works by fitting the typical hinged lid with a series of levers and springs, which activate via motion-detecting devices in the coffin, ultimately releasing the latch.

Any motion is detected through two mechanisms: a ring slipped around the occupant's finger and a metal head plate. Both are connected by wires to the coffin's opening mechanism, with the slightest movement triggering the lid catch.

In addition to the opening mechanism, the life-preserving coffin also features a mesh in its lid which would supposedly provide a limited supply of air post-burial.

Back from the dead

Check out the key components of this unusual Victorian coffin



Air mesh
A special grille is installed in the lid, enabling anyone inside to breathe for long enough to escape.

Head plate
A head plate is placed against the supposedly deceased's brow. It triggers the spring catch should it be disturbed.

Ring
A ring slips around one of the occupant's fingers. It is connected via wires to the spring latch.

© Corbis; Getty

The Sony Walkman

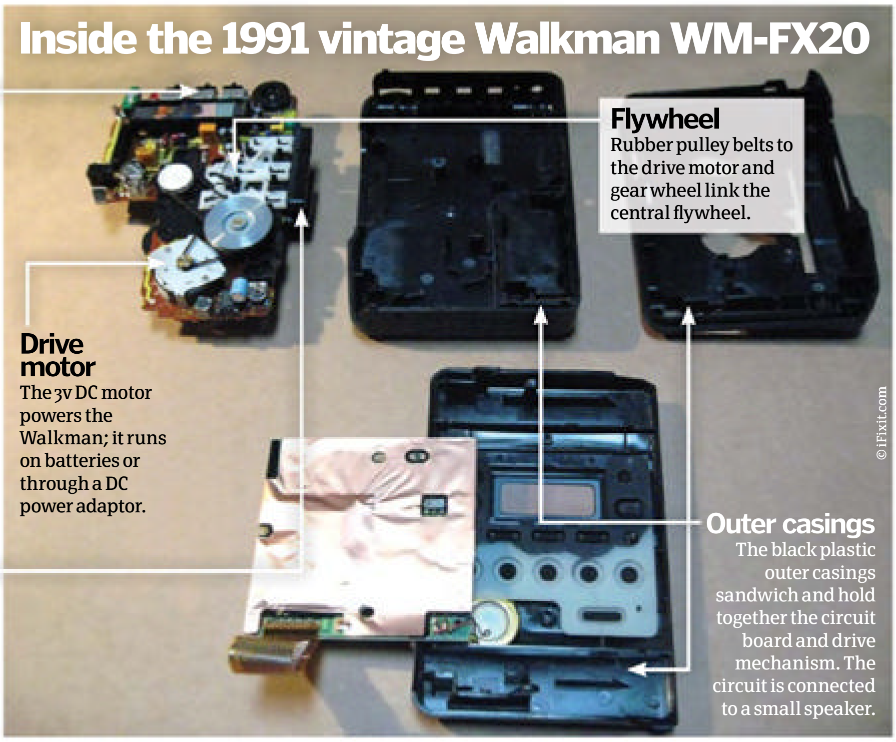
Inside the world' first commercial portable and personal stereo cassette player

For 20 years after its introduction in 1979, the Walkman dominated the personal stereo market. The first Walkman (TPS-L2) had two mini headphone jacks that enabled two people to simultaneously listen to it through Sony's new lightweight 50-gram (1.8-ounce) MDR-3L2 headphones.

The blue and silver metal-cased unit measured 88 x 133.5 x 29mm (3.5 x 5.25 x 1.15in), weighed only 391 grams (13.8 ounces) and was powered by two AA batteries, making it light, compact and easily portable. It could also be powered by a 3v DC adaptor (which wasn't supplied with the Walkman).

It contained a stereo tape head that played standard compact audiocassette tapes at a frequency response rate of 40Hz-12kHz. 300 to 500 different Walkman models have been produced that have since included new media formats like MiniDiscs and CDs, but it was only in 2010 that the cassette-based Walkman ceased production in Japan. New rivals like the introduction of Apple's iPod digital music player in 2001 and the increasing sophistication of mobile phones helped put the Walkman brand in the shade.

Inside the 1991 vintage Walkman WM-FX20



Additional controls
There is one headphone socket and a rotating volume control. Three push buttons change the mode from tape deck to radio, normal to metal audiocassette tape, and FM to AM radio stations. It also includes an LCD digital alarm clock.

Controls
There are three push-button Play, Rewind and Fast-Forward controls. Next to them is the Stop/Eject button, which opens the front panel to insert or remove an audiocassette from the machine.

Drive motor
The 3v DC motor powers the Walkman; it runs on batteries or through a DC power adaptor.

Flywheel
Rubber pulley belts to the drive motor and gear wheel link the central flywheel.

Outer casings
The black plastic outer casings sandwich and hold together the circuit board and drive mechanism. The circuit is connected to a small speaker.

© iFixit.com

Hearing aid evolution

Find out why modern electronic hearing aids were made possible by Alexander Graham Bell and his telephone

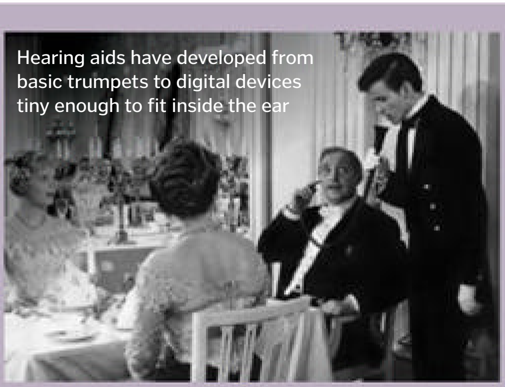
Up until the late-19th century, hearing aids were little more than just passive tubes that relied entirely upon capturing sound waves and funnelling them as much as possible towards the ear.

It wasn't until the invention of the telephone, which contained technology capable of converting sound energy into an electrical signal, that advances in hearing aid devices were made possible. This could then be amplified and sent to a speaker positioned near, or inside, the user's ear.

The key piece of tech was the carbon transmitter, invented independently by Thomas Edison, Emile Berliner and David Hughes, but Edison was awarded the first patent. The transmitter contained carbon granules, which reduce their electrical resistance when compressed by the pressure generated by sound waves. Miller Reese Hutchison used this device in 1898 to create the Akouphone, the first electric hearing aid.

Carbon transmitter hearing aids were very bulky, but the invention of smaller amplifiers – first the vacuum tube and later on the transistor – allowed for increasingly portable devices. Transistors were not only smaller, but they also consumed less power, meaning battery size could be reduced, making hearing aids ever-more practical for users.

The development of computers – particularly microprocessors – allowed hearing aids to be digitised. This enabled the incoming sound to be processed before being sent to the speaker, allowing the signal to be separated, with individual frequencies modulated to boost weak sounds and adjustments made according to incoming pitch and volume.



Hearing aids have developed from basic trumpets to digital devices tiny enough to fit inside the ear

© Alamy

Direct to the brain

Today's hearing aid technology is more advanced than ever. A cochlear implant is commonly used to deliver electrical signals through the cochlea to the auditory nerve. But if the nerve itself is damaged, auditory brainstem implants may be used instead. The cochlear nucleus is the area of the brain responsible for processing signals from the auditory nerve and can be stimulated artificially with electrodes. A processor is worn on the outside of the ear and transmits a signal to a receiver, implanted just beneath the skin. The receiver is connected to a silicon-coated implant array, which terminates on the brainstem, directly stimulating the nerves so sound can be perceived.

How did the first electric refrigerators work?

Often taken for granted today, once refrigerators were a groundbreaking and luxury appliance

Back in the Twenties, one electric refrigeration company dominated the market: Kelvinator. Its wooden cold box/compressor combo cost $714 (nearly $9,800/£6,100 today) – way beyond the pocket of the average household. So, with the goal of bringing more affordable refrigerators to the masses, General Electric ploughed $18 million into making the GE 'Monitor-top' fridge.

They were called Monitor-tops because the cabinet was all steel and the condenser was sealed in a cylindrical enclosure on top, which made it look like the turret from a 19th-century ironclad warship – the USS Monitor.

These refrigeration units worked under the same principles as modern fridges. By using a compressor, a circulating refrigerant was transformed from vapour into a liquid and cooled to near-room temperature under pressure, before being released back into circulation. The sudden change in pressure caused the refrigerant to turn into a vapour again, which had to draw heat from the air inside the cabinet, ultimately cooling it.

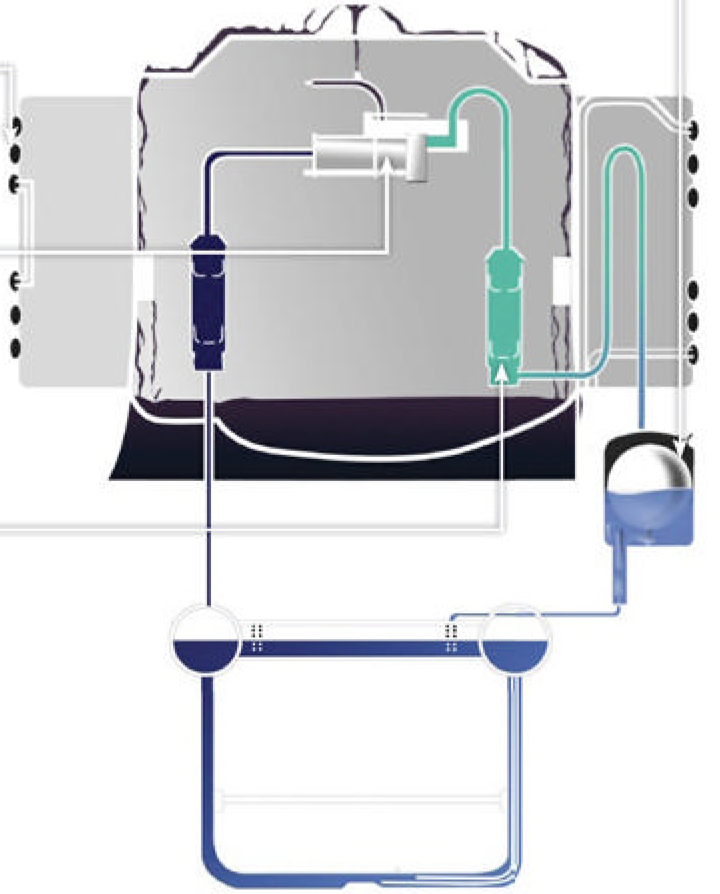
Several models of the Monitor-top were made, including two and three-door units, but the most popular was the single-door variant, which originally sold for $300 in 1927.

Toxic origins

Today, the inert tetrafluoroethane gas R134a is commonly used in fridges and freezers, but in the Twenties refrigerants like sulphur dioxide, methyl formate and methyl chloride were used. These are quite toxic: sulphur dioxide causes burns on contact and can damage vision, methyl formate is highly flammable, while methyl chloride, or chloromethane, can cause dizziness, nausea and even seizures at high concentrations. These nastier chemical refrigerants were replaced by Freon, a relatively harmless gas that, nevertheless, was banned in the production of new fridges in 1990 over concerns about CFCs' effect on the ozone layer. Monitor-top fridges have become quite collectable now, the steel build ensuring many have survived for nearly a century. They are usually converted, with the dangerous gases removed and a modern compressor system installed to be eco-friendly.

Inside a Monitor-top fridge

Discover the major components that made up one of the first commercial refrigerators

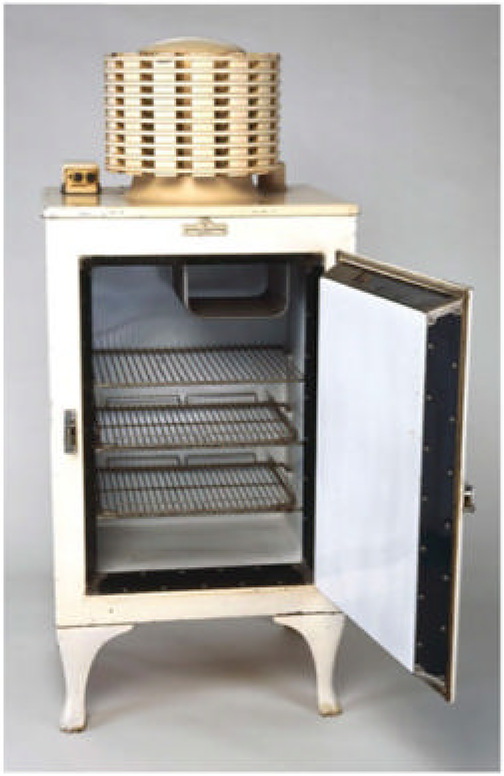


Refrigerant vapour
The cool refrigerant liquid is passed through a valve and expands back to a partial gas state, taking heat from the air in the cabinet in the process.

Heat-exchanging pipes
The liquid refrigerant, warm from compression, is passed around a series of pipes and cooled to room temperature.

Compressor pump
This pushes the refrigerant around the unit and compresses the refrigeration vapour.

Liquid refrigerant
The compressor applies pressure to the methyl formate gas in the Monitor-top fridge, which transforms it into a liquid.



© Getty

How Leonardo da Vinci tried to fly

Discover the secrets behind the legendary inventor's incredible flying machine

Few individuals truly fit the much-overused sobriquet of 'man ahead of his time', but Leonardo da Vinci is one of the select band who undoubtedly fits into this category. His mind seemed to be of another time entirely, devising all sorts of inventions that would either pre-empt or form the basis for modern-day equivalents. The item that perhaps best of all encapsulates his capacity to work beyond the constraints of his time, however, is his visionary ornithopter flying machine.

Having spent much time watching and studying the flight of birds, he observed the different ways they flapped their wings while taking off and in mid-flight, and sought to mimic them in the construction of his ornithopter. Sharing similarities with the paragliders of today, it required a solo pilot to manually operate a system of pullies, levers and pedals with his hands and feet in order to simulate flight. A hand crank increased the production of energy and the wings were designed to flap – much like those of a bird.

However, while it looked impressive on the page, da Vinci's ornithopter was never physically realised in his day. While it may well have worked while in flight, the task of actually taking off proved to be an insurmountable obstacle, as there wasn't a known way of producing enough power to actually get it off the ground.

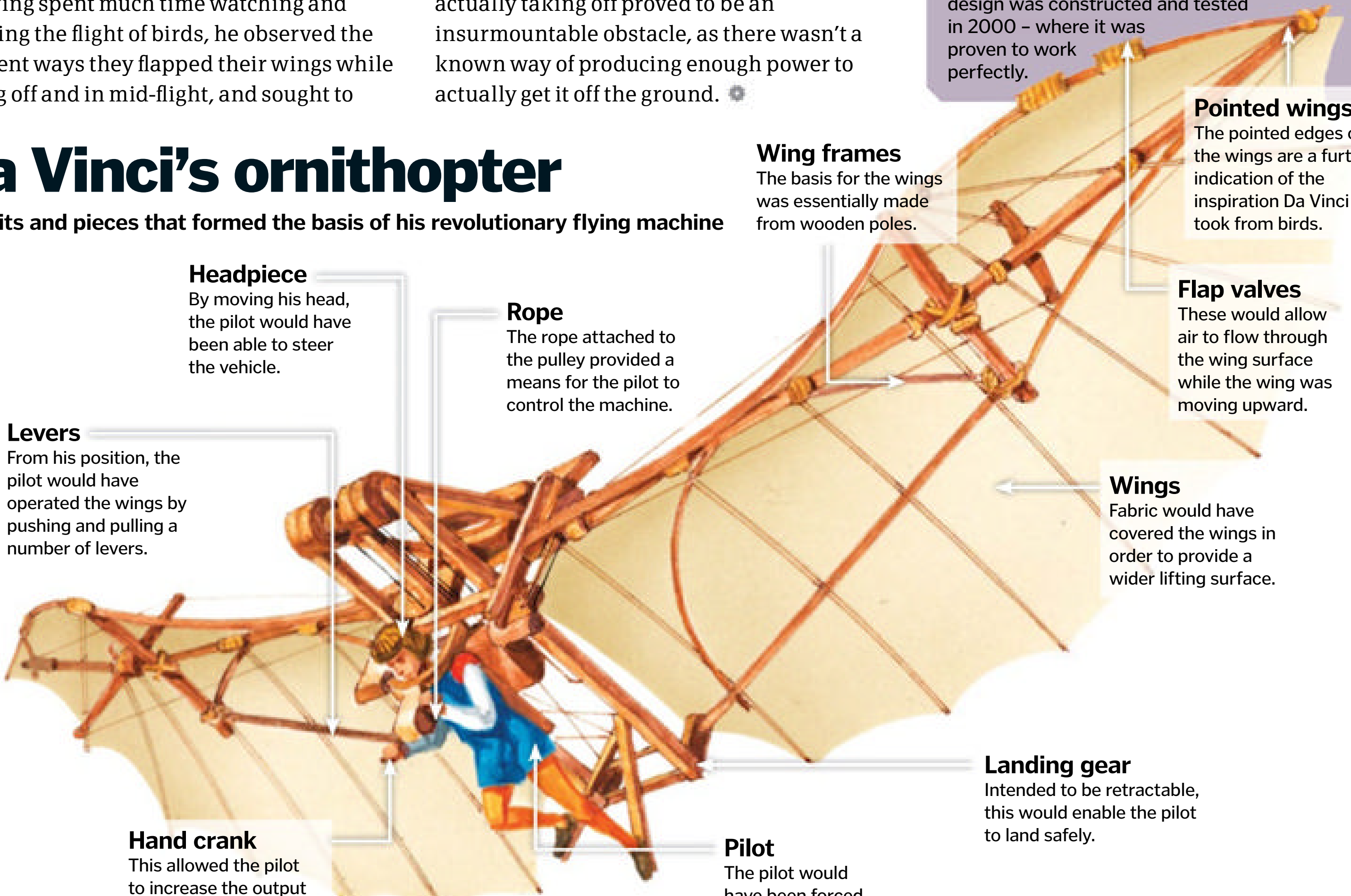
Da Vinci's other flying machines

Da Vinci didn't limit his pursuit of flight to just his ornithopter. Predating its invention by over 400 years, one of his designs reveals something akin to a modern-day helicopter. Also known as an aerial screw, its blades revolved like a corkscrew, compressing air in order to gain flight – a principle shared by its eventual successors. Although the theory was sound, modern-day scientists believe that it would have been too heavy to achieve flight, and as such remained strictly in the drawing book.

He is also credited with devising early designs for what would become what we know as the parachute. Despite its triangular shape and wooden frame causing many to doubt its effectiveness, it a prototype based on the same design was constructed and tested in 2000 – where it was proven to work perfectly.

Da Vinci's ornithopter

The bits and pieces that formed the basis of his revolutionary flying machine



Headpiece
By moving his head, the pilot would have been able to steer the vehicle.

Levers
From his position, the pilot would have operated the wings by pushing and pulling a number of levers.

Rope
The rope attached to the pulley provided a means for the pilot to control the machine.

Wing frames
The basis for the wings was essentially made from wooden poles.

Pointed wings
The pointed edges of the wings are a further indication of the inspiration Da Vinci took from birds.

Flap valves
These would allow air to flow through the wing surface while the wing was moving upward.

Wings
Fabric would have covered the wings in order to provide a wider lifting surface.

Landing gear
Intended to be retractable, this would enable the pilot to land safely.

Pilot
The pilot would have been forced to lie still where he was positioned.

Hand crank
This allowed the pilot to increase the output of energy from the flying machine.

© Thinkstock

5 TOP FACTS
FIRE

Neolithic times
1 The earliest fire-making method consisted of twirling a pointed stick in a wooden block, creating an ember to light tinder. Iron pyrite rocks were also struck against flint.

Solar power
2 Using reflective surfaces to focus sunlight on tinder was known in ancient times. Experiments with mirrors/lenses were conducted to develop deadly weapons.

Tinderbox
3 In the Middle Ages, it was found that a spark is created by striking steel and flint. The portable tinderbox caught the spark in tinder and then ignited a small piece of wood.

Friction matches
4 English chemist and apothecary John Walker sold the first friction matches in 1827. They could be ignited by striking the head of the match against any rough surface.

Safety matches
5 In 1844, Gustaf Erik Pasch developed the first safety match. The head contained potassium chlorate, reacting when struck against a surface coated with red phosphorus.

DID YOU KNOW? *The 'His Master's Voice' image of Nipper the dog listening to a gramophone originally featured a phonograph*

How the gramophone worked

The invention that brought sound to the home explained

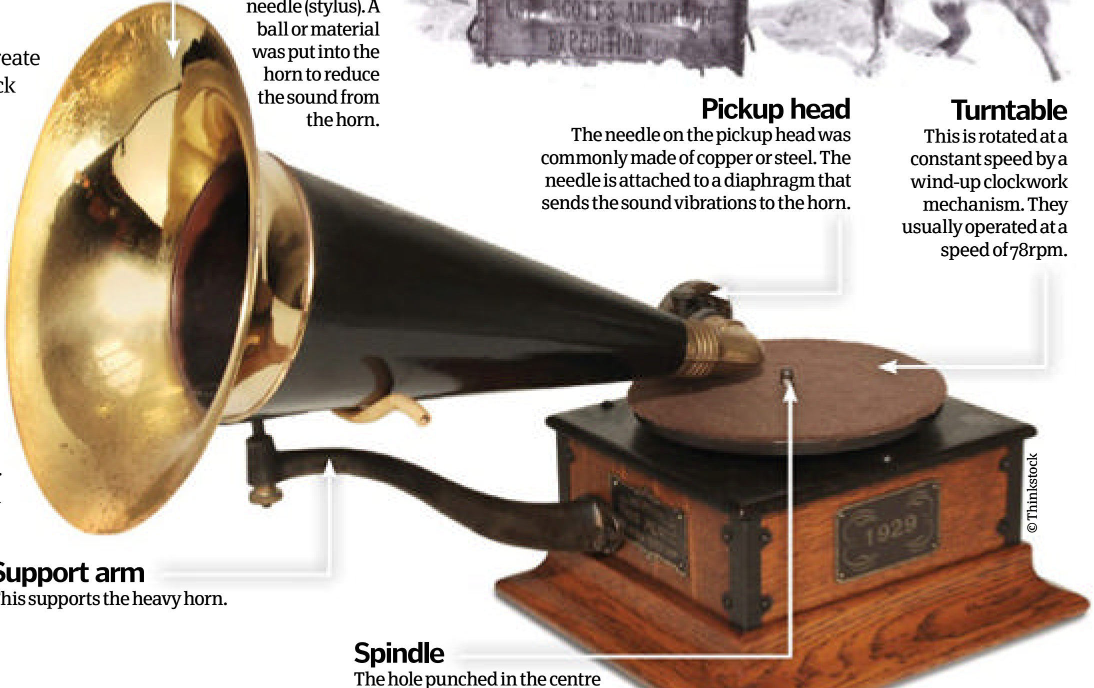
In the 19th Century, there was fierce competition in Europe and the USA to create machines that could record and playback music and sounds. As early as 1857, the phonautograph, created by Édouard-Léon Scott de Martinville, used a diaphragm attached to a bristle that responded to sound vibrations. These vibrations were traced onto a sheet of paper coated in soot, which was wrapped around a rotating cylinder. This, however, could not play back the recording.

In 1877, Thomas Edison's phonograph followed a similar principle to the phonautograph, but used tinfoil wrapped over a grooved cylinder. The vibrations of a needle attached to a diaphragm and horn made indentations in the foil, and to play it back the needle retraced the indentations in the foil. Wax cylinders enabled such recordings to be played back more than once.

Ten years later, Emil Berliner introduced the gramophone that used discs with a spiral groove, rather than a cylinder to record and play back the sound. It still used a horn and needle, but unlike cylinders, the master recording could be easily copied onto a mould and mass-produced. The gramophone came to dominate the market in the Twenties, superseded by the electronic record player.

Sled dog and gramophone, Terra Nova Expedition

Anatomy of a gramophone



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Horn
Amplifies and projects the sound from the needle (stylus). A ball or material was put into the horn to reduce the sound from the horn.

Pickup head
The needle on the pickup head was commonly made of copper or steel. The needle is attached to a diaphragm that sends the sound vibrations to the horn.

Turntable
This is rotated at a constant speed by a wind-up clockwork mechanism. They usually operated at a speed of 78rpm.

Support arm
This supports the heavy horn.

Spindle
The hole punched in the centre of the record disc is placed over the spindle. This keeps the record from spinning off the turntable as it rotates.

The bow drill

An ancient device that uses friction to light fires

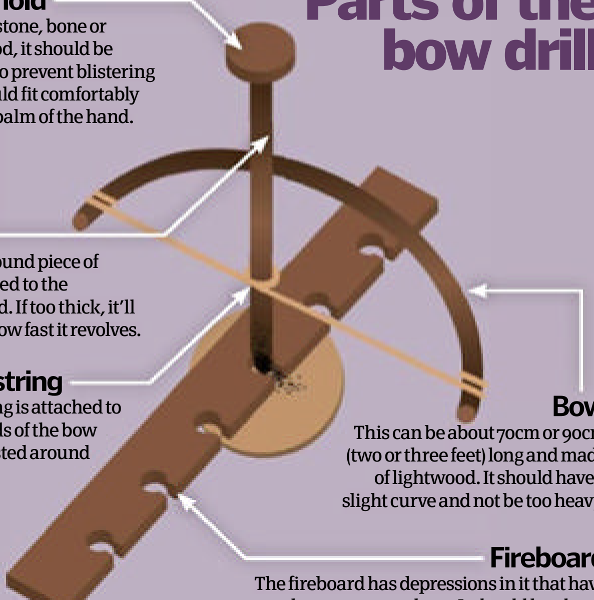
The bow drill works by pressing down on the handhold at the top of the drill with one hand, while moving the bow horizontally backwards and forwards with the other hand. This makes the drill revolve fast enough to create friction and heat on the fireboard.

The hot sawdust produced by this action falls down the notch at the side of the fireboard and ignites dry leaves or other tinder material. Once this is lit, the burning tinder can be removed and used elsewhere.

The Ancient Egyptians used the bow drill as long ago as 3000BC, with the bow string wrapped several times around the drill, to produce holes in wood and stone rather than to light fires. Carpenters are even depicted using this device on the fifth dynasty tomb of an important official called Ti, at Saqqara.

© Science Photo Library

Parts of the bow drill



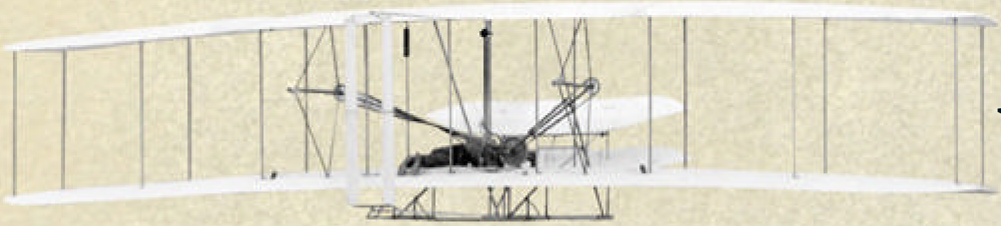
Handhold
Made of stone, bone or hardwood, it should be smooth to prevent blistering and should fit comfortably into the palm of the hand.

Drill
A thin, round piece of wood fitted to the handhold. If too thick, it'll reduce how fast it revolves.

Bow string
The string is attached to both ends of the bow and twisted around the drill.

Bow
This can be about 70cm or 90cm (two or three feet) long and made of lightwood. It should have a slight curve and not be too heavy.

Fireboard
The fireboard has depressions in it that have notches cut next to them. It should be placed on a dry base to protect it from damp ground.



The Wright brothers 136

INFLUENTIAL FIGURES

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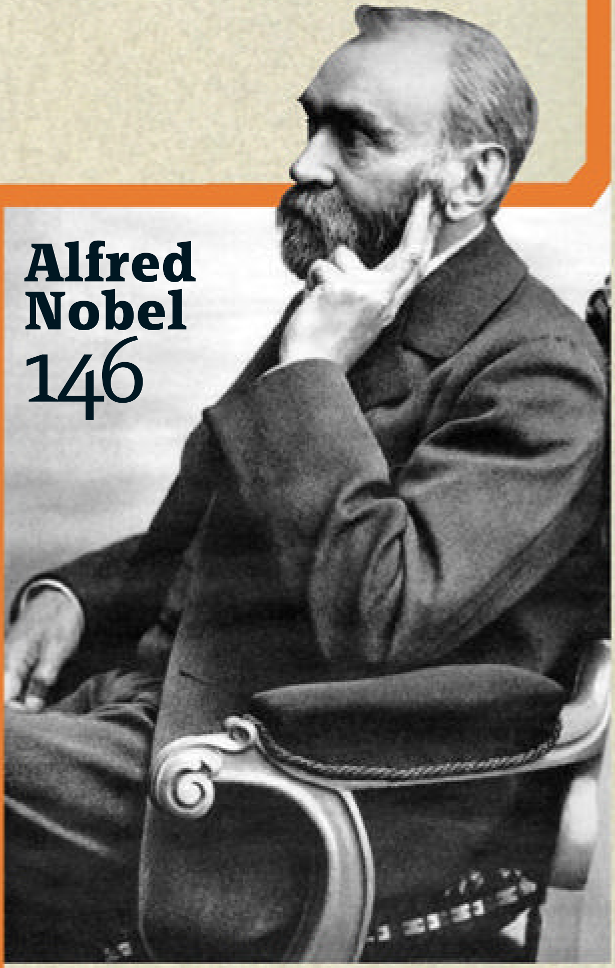

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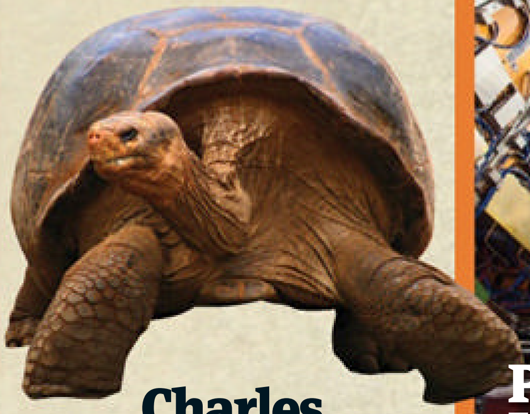

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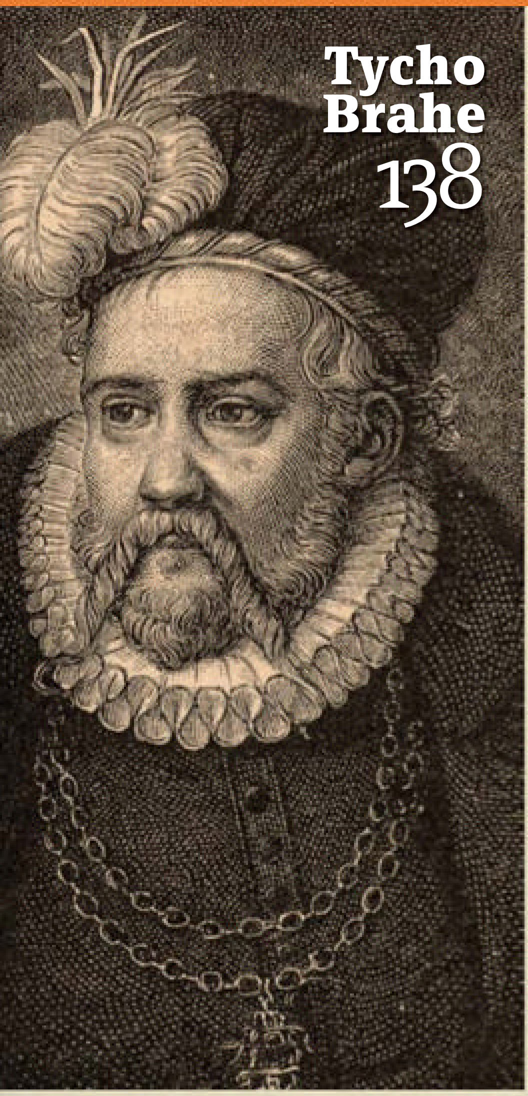

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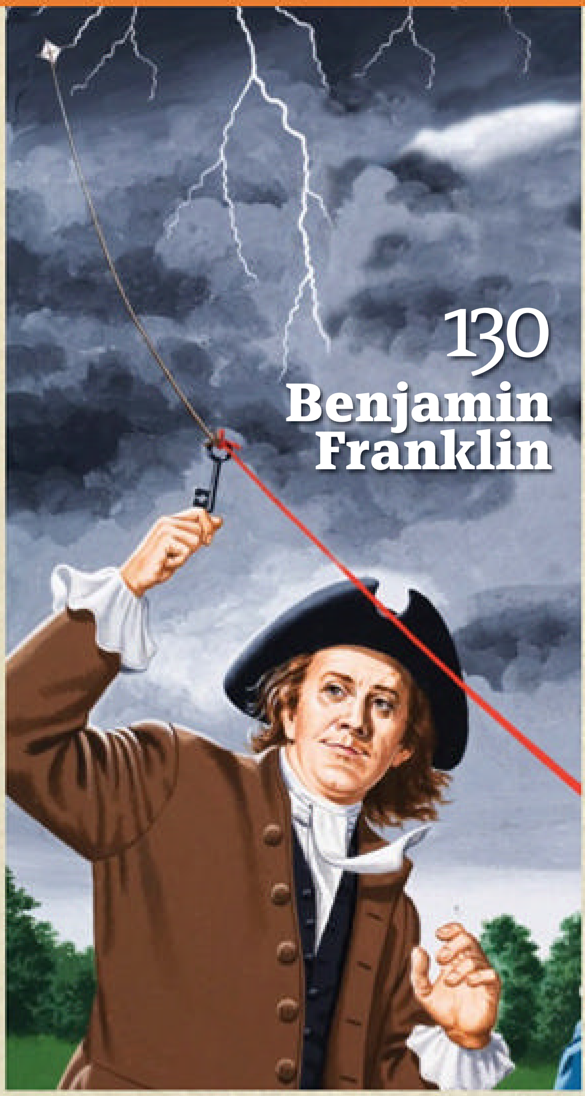

130 **Benjamin Franklin**

132 **Isambard Kingdom Brunel**

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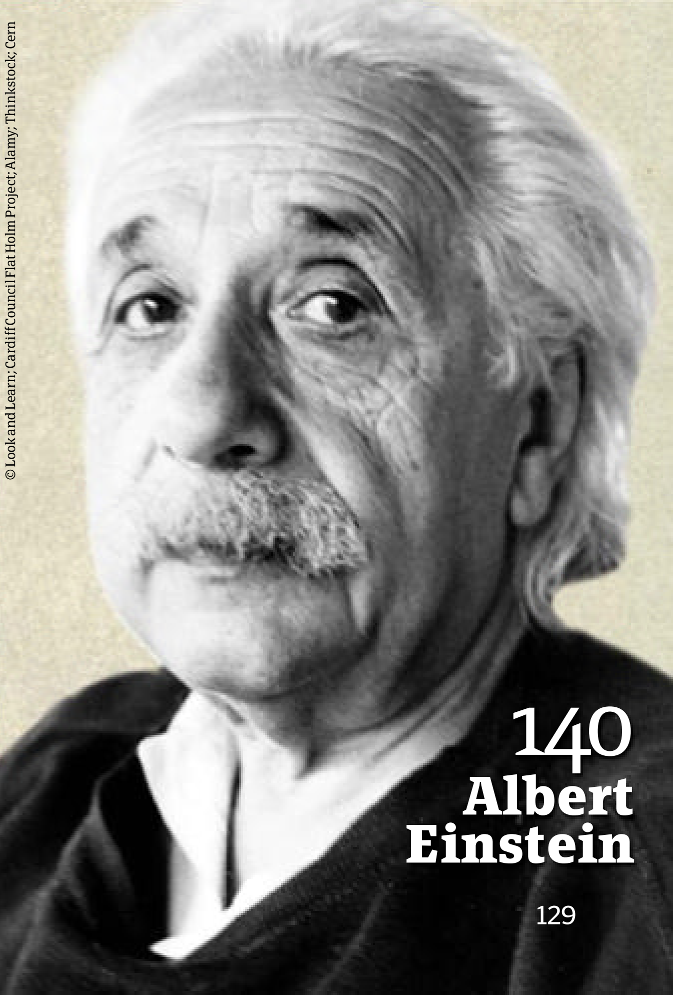
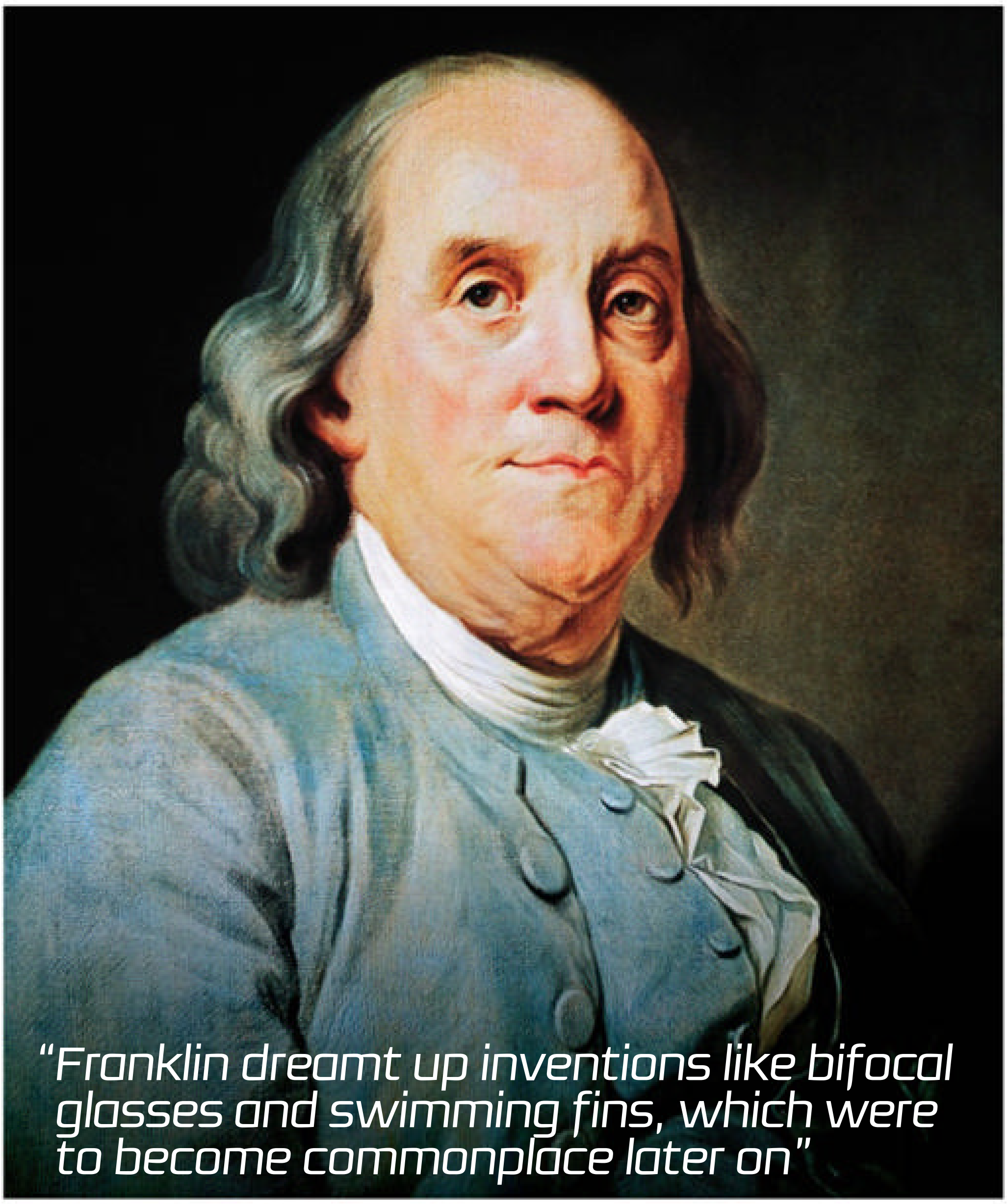


140 **Albert Einstein**

Benjamin Franklin

How the man on the $100 bill revolutionised technology just as much as American politics



> "Franklin dreamt up inventions like bifocal glasses and swimming fins, which were to become commonplace later on"

Benjamin Franklin, one of the greatest minds of all time, had his first big break while pretending to be a woman. At 12 years old, he began an apprenticeship at his brother James' printing shop, which published the first independent newspaper in the colonies. But despite Benjamin's determination and hard work, James refused to print any of his articles. Instead, the young Franklin began writing under the pseudonym 'Mrs Silence Dogood', regularly sending letters to the paper for publication. 'Her' witty and insightful commentary became the talk of the town, but James was outraged when he discovered that the true author was in fact his younger brother. Benjamin Franklin abandoned his apprenticeship and moved to Philadelphia, where he set up his own printing business and purchased *The Pennsylvania Gazette*.

The 1730s saw his prominence and success grow, especially with his publication of the *Poor Richard's Almanack*. Franklin bought properties and businesses, organised a volunteer fire department, established a lending library and was elected grand master of the Pennsylvania Masons, clerk of the state assembly and postmaster of Philadelphia. He also began to expand into entrepreneurship, and in 1741 he invented the Franklin stove – a heat-efficient fireplace that aimed to produce less smoke and more heat than the ordinary open fireplaces on the market. While the stove failed to take off, in 1749 he retired from business to concentrate more on his inventions, dreaming up things like bifocal glasses and swimming fins that were to become commonplace. Never one to rest on his laurels, Franklin then turned his attention to the study of electricity, and in 1752 conducted the famous kite-and-key experiment, which proved that lightning was made up of static electricity. He also developed the single fluid theory, which proposed that electricity was a 'common element' rather than two opposing forces.

The 1750s saw Franklin become more involved in politics. In 1757, he travelled to England to represent Pennsylvania in its fight with the

A life's work

We travel through the key events in the famous polymath's career

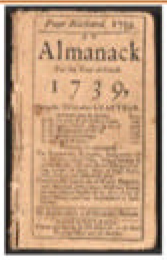
1706
Franklin is born in Boston on 17 January to Josiah Franklin and his wife Abiah.

1718
At the age of 12, Franklin begins an apprenticeship at his brother's new printing business.

1723
After publishing work under a false name, Franklin runs away to Philadelphia.

1728
Franklin establishes his own printing company and purchases *The Pennsylvania Gazette* the following year.

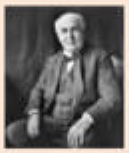
1732
Franklin publishes the first edition of the *Poor Richard's Almanack*, which quickly becomes very popular.



IN THEIR FOOTSTEPS…

Michael Faraday

Born the year after Franklin died, he built on Franklin's work in his own experiments. He discovered electromagnetic induction and his Faraday cage, which blocks electric fields, was largely based on one of Franklin's experiments, where he dangled a cork ball into a metal cup to discover it was only attracted to the exterior, not the interior.

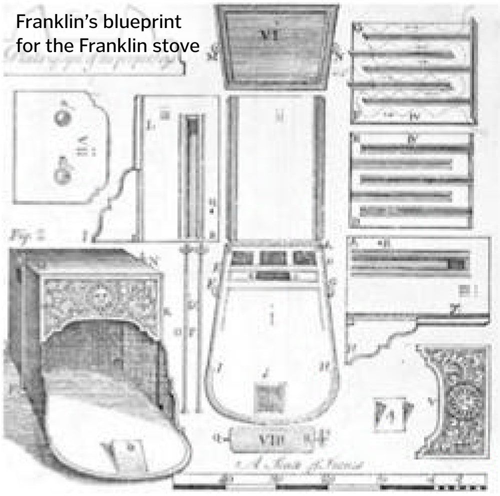


Thomas Edison

Edison was also devoted to the study of electricity. He discovered the 'Edison effect', or the heat-induced flow of an electric charge through space. This allowed for the invention of things like radios, TVs and other wireless products. Though he didn't actually invent the light bulb, he did develop a more practical incandescent bulb.

DID YOU KNOW? *Franklin remained a printer to his end, and wherever he lived he made sure he had a printing press to hand*

Benjamin Franklin invented the bifocals



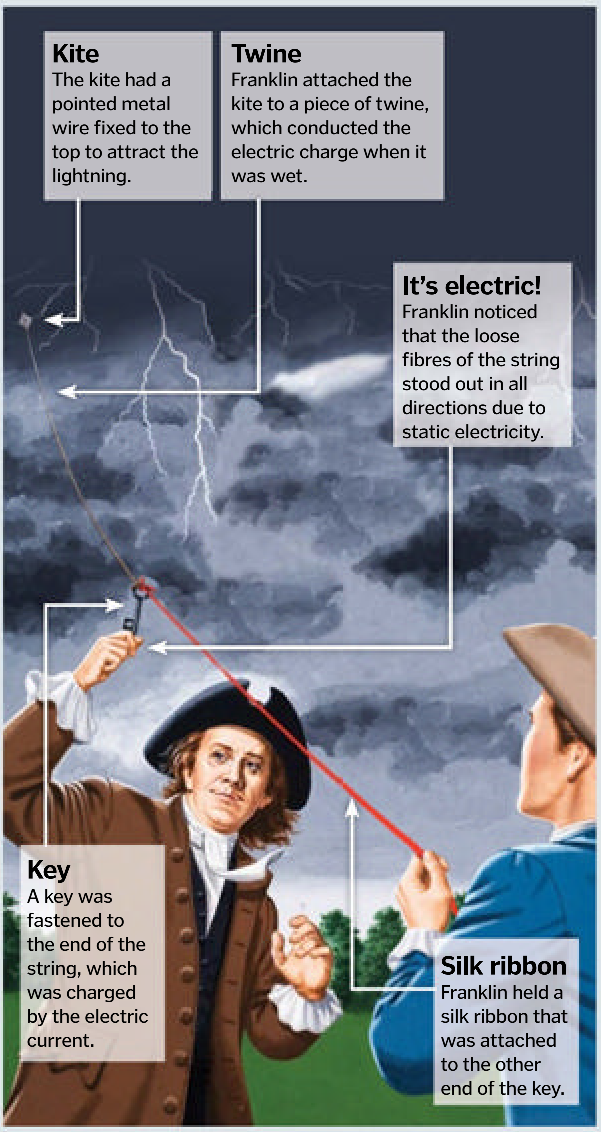
Franklin's blueprint for the Franklin stove

descendants of the Penn family over who should represent the colony. On his return almost 20 years later, he fought fiercely for American sovereignty, and was one of the five people who drafted the Declaration of Independence in 1776. Later that year he went to France as a diplomat for the United States where he became a much-loved figure, and it was largely because of him that the government of France signed a Treaty of Alliance with the USA in 1778.

When Franklin died in 1790, he was dubbed 'the harmonious human multitude.' The legacy of his inventions and political work lives on to this day.

The big idea

Before Franklin began his experiments in science, the popular belief was that electricity consisted of two opposing forces. Franklin proved that in fact it was a single element, imagining it to be like an invisible fluid. If a body had an excess of this fluid, it was positively charged. If it had a deficiency, it was negatively charged. He theorised that the body with more fluid flowed to the body with less fluid, or rather that electric charges flowed from positive to negative. However, it has since been discovered that electricity is actually the flow of electrons, which means it flows from negative to positive.



Kite
The kite had a pointed metal wire fixed to the top to attract the lightning.

Twine
Franklin attached the kite to a piece of twine, which conducted the electric charge when it was wet.

It's electric!
Franklin noticed that the loose fibres of the string stood out in all directions due to static electricity.

Key
A key was fastened to the end of the string, which was charged by the electric current.

Silk ribbon
Franklin held a silk ribbon that was attached to the other end of the key.

Five Franklin inventions

1 Bifocals

Franklin suffered from poor eyesight, but came up with the brilliant idea of creating glasses with a separate upper and lower half; the upper for distance and the lower for reading.

2 Lightning rod

After studying the behaviour of electricity, Franklin designed a metal rod that could be attached to the tops of buildings and connected to the ground through a wire to discharge lightning.

3 Glass armonica

A popular form of entertainment in the 18th century was playing music using wine glasses filled with water. Franklin invented a mechanised version consisting of 37 glass bowls.

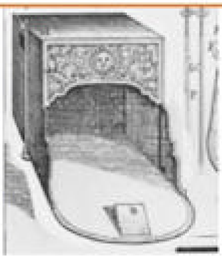
4 Franklin stove

This metal-lined fireplace stood in the centre of the room, radiating heat in all directions. It provided more heat, used less wood and produced less smoke than open fireplaces.

5 'Long arm'

Franklin loved reading and established a number of libraries. His idea for a wooden pole with a grasping claw at the end helped visitors to reach books on the top shelves.

1741
The efficient Franklin stove is invented but fails to take off as a product.



1752
Through his kite experiment, Franklin proves lightning is an electrical phenomenon.

1776
Franklin signs the Declaration of Independence, signalling the United States' independence from the British Empire.

1783
The Treaty of Paris is signed, ending the American Revolutionary War.

1790
Franklin dies on 17 April aged 84. Over 20,000 mourners attend his funeral.

© Look and Learn; Corbis; Getty; Moses King, 1881; Louis Bachrach

Isambard Kingdom Brunel

Though not always successful, Brunel's designs revolutionised transport, and he is now remembered as one of the greatest engineers of all time

Isambard Kingdom Brunel revolutionised rail and water transport not just in the UK but all around the world

> "SS Great Britain laid the foundations for a new era of transatlantic travel"

While an era of progress, the Industrial Revolution was also a time of trial and error. Those leading the way in technological advances attempted to make huge leaps forward, often resulting in failure, but sometimes incredible success. One of the greatest of the innovators of this time was Isambard Kingdom Brunel, born at the start of the 19th century. His father, Marc, was a French civil engineer, and encouraged his son to learn arithmetic, scale drawing and geometry. At 16, he became a watchmaker's apprentice.

In 1824 Marc was appointed chief engineer of a project to construct a tunnel under the River Thames. He hired his son as an assistant engineer, who later became resident engineer. The project was fraught with disaster, witnessing several incidents of flooding, as well as financial difficulties. At one point the operation was halted for several years and the tunnel bricked up. It was eventually opened in 1843 and is still in use today as part of the London Overground network.

The project transformed the young Brunel into a full-fledged engineer. In 1830 he entered a competition to design a bridge that would span across the River Avon in Bristol, and although rejected initially, he eventually persuaded the panel to appoint him as project engineer. Work on the Clifton Suspension Bridge commenced in June 1831, but just four months later the Queen Square riots drove investors away. Once again a project ground to a halt.

In 1833 Brunel was made chief engineer of the Great Western Railway, which would run from London to Bristol. It was then that he developed one of the most controversial ideas of his career – to use a 2.1-metre (seven-foot) gauge (distance

A life's work

Brunel made his mark on history – but what were the defining moments in this innovator's career?

1806
Isambard Kingdom Brunel is born in Portsmouth, UK, to French civil engineer Marc Isambard Brunel and Sophia Kingdom.

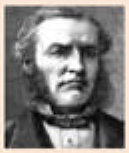
1827
Brunel is appointed resident engineer of the Thames Tunnel project in London, taking over from his father.

1830
He enters a competition to design a bridge to span the River Avon and is awarded first place.

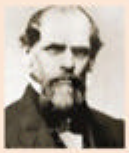
1831
Work on the Clifton Suspension Bridge begins but financial difficulties bring the project to a halt.

1833
Brunel becomes chief engineer of the Great Western Railway, developing his idea for a wider track.

IN THEIR FOOTSTEPS…



Edward Harland
He formed Harland and Wolff Heavy Industries Ltd with Gustav Wolff in 1861, to build ocean liners. Harland built on Brunel's design, replacing wooden decks with iron ones for strength and giving the hulls a flatter bottom for capacity. In 1899, construction of the Oceanic began. At 215m (705ft) long, it was the first ship to exceed Brunel's Great Eastern.

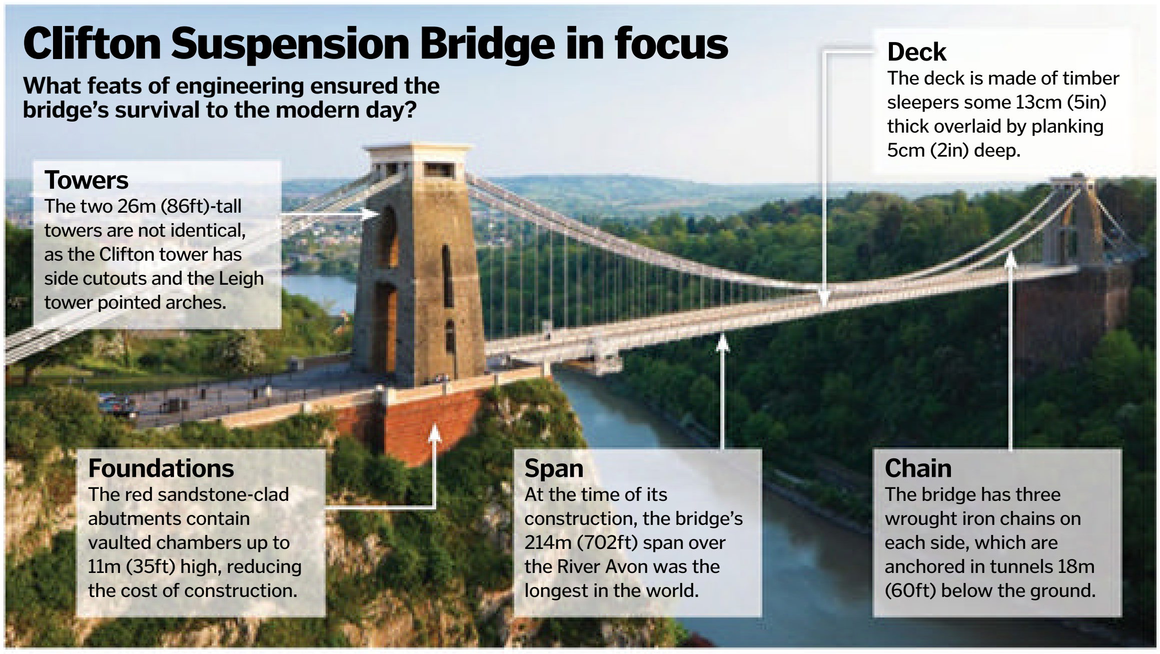


John Roebling
Born in the same year as Brunel, in 1841 Roebling began producing wire rope and in 1844 designed a replacement for a wooden aqueduct. The bridge was supported by a continuous cable of wires bound together, which is now the standard for bridge design. Roebling built many suspension bridges, including the Brooklyn Bridge.

DID YOU KNOW? *Brunel University in Uxbridge, London, established in 1966, is named after Brunel*

Clifton Suspension Bridge in focus

What feats of engineering ensured the bridge's survival to the modern day?



Towers
The two 26m (86ft)-tall towers are not identical, as the Clifton tower has side cutouts and the Leigh tower pointed arches.

Deck
The deck is made of timber sleepers some 13cm (5in) thick overlaid by planking 5cm (2in) deep.

Foundations
The red sandstone-clad abutments contain vaulted chambers up to 11m (35ft) high, reducing the cost of construction.

Span
At the time of its construction, the bridge's 214m (702ft) span over the River Avon was the longest in the world.

Chain
The bridge has three wrought iron chains on each side, which are anchored in tunnels 18m (60ft) below the ground.

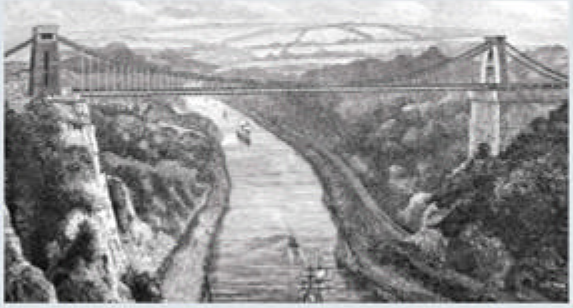
between the tracks) rather than the standard 1.4-metre (4.6-foot) gauge. He believed that this would allow the trains to run at much higher speeds, as well as provide a more stable and comfortable journey. For the rest of his life the efficiency of this design was heavily contested.

But none could contest the efficiency of his Great Western Steamship, which transported passengers from Bristol to New York. It was thought a steamship would not be able to carry enough fuel for the trip and have room for cargo. However, it completed its maiden voyage in 15 days, with a third of its coal remaining. Brunel was also a fierce proponent of propeller-driven ships and incorporated a propeller on his second ship, SS Great Britain. Considered the first modern ocean-going ship, it was made of metal, powered by an engine rather than wind, and driven by a propeller rather than a paddle wheel. Indeed, this vessel laid the foundations for a new era of transatlantic travel.

Brunel's personal life was a series of ups and downs too. Many say the stress of the Great Western Railway led to his early death in 1859. Soon after Brunel's death it was decided that all railways in the country should revert to using the standard gauge. However, funds were also raised to complete the Clifton Bridge, which was finally opened five years after Brunel's death and is still in use to this day. ⚙

The big idea

The Clifton Suspension Bridge in Bristol spans 214m (702ft) between two 26.2m (86ft) towers, which then was the longest bridge span in the world. In its design of chains and rods, Brunel had made a near-perfect calculation of the minimal weight required to provide maximum strength. The abutments contain a honeycomb of chambers and tunnels, some of which are 11m (36ft) high, which reduced the cost of construction without compromising strength.



Brunel trivia

1 French connection

During his teenage years, Brunel attended school in France, but his application to the renowned French engineering school École Polytechnique was rejected because he was a 'foreigner'.

2 River party

In 1827, after several incidents of flooding, Brunel held a lavish banquet inside the Thames Tunnel to help convince people that it was perfectly safe.

3 Beating the competition

Brunel's submission to the Clifton Bridge competition was initially rejected by the judge, Thomas Telford, who instead put forward his own design.

4 Flip of a coin

In 1843, while performing a magic trick for his children, a coin became lodged in his windpipe. To remove it, Brunel was strapped to a board and turned upside down.

5 Lady with the lamp

In 1855 he responded to a request from Florence Nightingale to design a new hospital to replace the unsanitary British Army Hospital in Scutari, Turkey, which he did successfully.

1838
The Great Western Steamship sails from Bristol to New York in just 15 days.

1843
The Thames Tunnel is opened to the public and the propeller-driven SS Great Britain is launched.

1852
Brunel's design for Paddington Station is constructed.

1859
Brunel dies on 15 September, ten days after suffering a stroke.

1864
The Clifton Suspension Bridge is finally completed as a tribute to Brunel by the Institute of Civil Engineers.

© Alamy; National Maritime Museum

Guglielmo Marconi

Sometimes called the father of radio, this resourceful inventor's practical telegraphy system led to the widespread use of wireless communications

Marconi developed his radio equipment in the attic of his parents' home in Italy, with the help of his butler, Mignani

> "The Marconi room aboard the RMS Titanic and its two Marconi wireless operators transmitted the most famous radio signals of all time"

Guglielmo Giovanni Maria Marconi was a widely respected Italian inventor who pioneered the development of wireless communication and long-distance radio transmission.

Often credited as the inventor of radio, Marconi was actually an astute businessman who combined, and built upon, the work of other scientists to develop a commercially viable method of long-distance communication.

His interest in electricity and physics began at an early age, and he was inspired by the work of scientists like James Clerk Maxwell, Heinrich Hertz and Nikola Tesla, among others.

In 1894, Marconi read the work of German physicist Hertz, who had developed equipment to send and detect electromagnetic waves over short distances. Marconi saw the potential for transmitting information using radio waves and set about developing a longer-range system to replace wire-based telegraphy.

Marconi began his experiments at his father's estate and with the help of his butler, Mignani, built equipment in the attic. Soon he could transmit radio waves over short distances, so he moved his experiments outdoors to develop the technology further. He found that increasing the length of the antennas – and arranging them vertically – increased the range of transmission so much that he was able to send and receive signals over distances of around 2.4 kilometres (1.5 miles).

It was at this point that Marconi began to see the potential commercial applications of his experiments. Italy already had a well-established telegraph system though, with networks of wires extending across the country, and his applications for funding were

A life's work

Tune in to some of the major events from the lifetime of this astute Italian radio pioneer

1874
Guglielmo Marconi is born in Bologna, Italy, to landowner Giuseppe Marconi and his Scots-Irish wife Annie Jameson.

1894
Begins to develop a method of transmitting telegraph messages without wires, using radio waves.

1896
Travels to London, where he gains the support of engineer-in-chief of the Post Office, William Preece.

1899
Sets up the first wireless link between Britain and France from Wimereux, France, to a lighthouse in Dover, England.

1900
Takes out his No 7777 'Improvements in Apparatus for Wireless Telegraphy' patent to protect his technological developments.

IN THEIR FOOTSTEPS...

Edwin Armstrong
Captivated by Marconi's radio technology, Armstrong was a prolific inventor and made the regenerative circuit – the first radio amplifier; it used a positive feedback loop to greatly amplify incoming radio signals. He also invented modern frequency modulation (FM) radio transmission, which enabled much clearer communication.

John Logie Baird
Baird was a pioneer in the development of publicly available television broadcasting, who compiled, tested and modified the work of others to produce a live, moving TV image. He once said of Marconi: "It was he who ventured forth like Columbus and forced upon the attention of the world the existence of a new means of communication."

DID YOU KNOW? *Marconi's wireless experiments disproved the dominant belief that the Earth's curvature affected transmission*

Post Office engineers inspect Marconi's radio equipment before the first-ever transmission of radio signals over the open sea

dismissed. Undeterred, Marconi travelled to the UK. Britain had a powerful Royal Navy and was the world's greatest trading empire, and his thinking was that they might have use for his work in maritime communication.

Marconi gained the support of the engineer-in-chief of the British Post Office and, with his help, demonstrated his technology to the British government. During his first few years in England he gradually improved the distance of radio transmission – first on land and then over sea. His work excited the international community and stations were set up in France for the first radio crossing of the Channel.

As his technology continued to evolve, 'Marconi rooms' were installed in ships, containing a suite of wireless telegraphy equipment which enabled communication with land as well as other vessels. The Marconi room aboard the RMS Titanic and its two Marconi wireless operators transmitted perhaps the most famous radio signals of all time: 'CQD CQD SOS Titanic position 41.44 N 50.24 W. Require immediate assistance. Come at once. We struck an iceberg. Sinking'.

Marconi died in Rome in 1937 at the age of 63. He was given a state funeral and – as a tribute to his massive contribution to wireless communication – every radio station in the world fell silent for two minutes.

The big idea

Marconi combined and modified the inventions of other scientists to develop equipment that could transmit radio waves over great distances. He used a spark-gap transmitter to generate radio frequency electromagnetic waves and a coherer receiver to detect them. A telegraph key enabled him to send radio waves in bursts, generating Morse code. Marconi discovered that the maximum distance of radio wave transmission varied according to the square of the height of the transmitting antenna – tall, vertical antennas were key.

Top 5 facts: Guglielmo Marconi

1 Royal connections

Marconi installed radio equipment on Queen Victoria's royal yacht so that she could communicate with the Prince of Wales (Edward VII).

2 Educated but unqualified

Marconi had no formal qualifications, but had a keen interest in physics. At the request of his mother, he was mentored by physicist Professor Augusto Righi, who introduced him to radio waves.

3 Are you ready?

The first radio transmission across the open sea was sent over the Bristol Channel and travelled a distance of 6.4 kilometres (four miles). It read 'Are you ready'.

4 High-speed Morse

To be employed as a wireless operator by Marconi's Wireless Telegraph Company you had to be able to send and receive Morse code at a speed of 25 words per minute.

5 Lucky escape

Marconi was offered free passage on the RMS Titanic, but decided to travel to America three days earlier on the RMS Lusitania because he had paperwork to do.

1901
Successfully transmits the letter 'S' in Morse code 3,380km (2,100mi) across the Atlantic Ocean to Newfoundland.

1909
Receives the Nobel Prize in Physics – along with Karl Ferdinand Braun – for their contribution to wireless telegraphy.

1912
Marconi radio is used to save victims of the Titanic, and passes distress signals from the sinking ship to the RMS Carpathia.

1914
Joins the Italian war effort during World War I, where he takes charge of the military's radio service.

1937
Marconi dies aged 63. He receives a state funeral in Italy and all radio stations hold a two-minute silence in his honour.

© Corbis; Jza84; Oast House Archive; Cardiff Council Flat Holm Project

The Wright brothers

These siblings played a pivotal role in the evolution of powered flight and radically altered the path of aviation history

Wilbur (right) and Orville attend the Belmont Park Aviation Meet, NY, in 1910

Wilbur and Orville Wright are two of history's most famous aviation pioneers who, through a series of experiments in the late-19th and early-20th centuries, created the first controllable, powered, heavier-than-air aircraft. Named the Wright Flyer, the plane was the culmination of over a decade's worth of research and trials that saw the brothers progress from custom-built kites, through to gliders and finally on to engine-powered aeroplanes. Together these talented siblings are generally credited with launching the age of powered flight.

Wilbur and Orville Wright were the sons of Milton Wright, an ordained minister of the Church of the United Brethren in Christ, and Susan Catherine Koerner Wright. The family lived in various locations including Richmond, IN; Cedar Rapids, IA; and Dayton, OH – the latter for the majority of the brothers' lives. Orville later explained that his father had encouraged both of them from an early age "to pursue intellectual interests and to investigate whatever aroused curiosity."

This encouragement led Orville and Wilbur into a diverse range of interests and expertise including printing, bicycles – which the pair sold and repaired for several years – and the construction of various machines from wood and metal. Both engineers and inventors, the brothers became well known for their academic and practical application of modern engineering, with Wilbur especially spending much time in his father's and public libraries.

One of their heroes was German gliding pioneer Otto Lilienthal, who up until his death in 1896 had built and flown a series of aircraft to varying degrees of success. His death, however – which was the result of a glider crash – oddly spurred the brothers' interest in flight, with them writing to the Smithsonian Institution for suggestions on other aeronautical manuscripts. One of the museum's recommendations was the engineer Octave Chanute, a leading authority on aviation and civil engineering at the time.

With Chanute's help the brothers began conducting a number of aeronautical experiments. Crucial to their approach was the focus on control of the aircraft, advancing previous designs that could only fly in a straight line by introducing a helical twist across the wings in either direction. The brothers tested this configuration in 1899 and, after discovering that it allowed the acute control of a kite, began working on a full-scale model: the first Wright Glider. It was tested in October 1900 at Kitty Hawk, NC, where although lifting off the ground, it produced disappointing results.

The Wright brothers refined their glider and tested it in 1901, then again in October 1902 after spending the summer undertaking a vast series of tests into more efficient wing designs. This third model was the breakthrough, with the glider performing exactly as predicted. The pair

The big idea

Prior to the Wright brothers' successful flight (pictured below), many other scientists and engineers had dreamed about and, to varying degrees of failure, attempted to build machines that could not only defy gravity, but do so in a controlled manner. Their failures left the idea of a non-dirigible method of flight as mere fancy, with materials, aerodynamics and energy supplies all seeming insurmountable obstacles.

What is testament to the Wright brothers' expertise is that they addressed each one of these issues with their aircraft in turn, solving in years what countless minds had failed to address in centuries. Examples include the testing of hundreds of wing designs in a custom-built wind tunnel to determine which shape best granted lift, designing and building their own four-cylinder internal combustion engine that was adapted for air travel and recognising that propeller blades could be understood as rotary wings.

Up, up & away

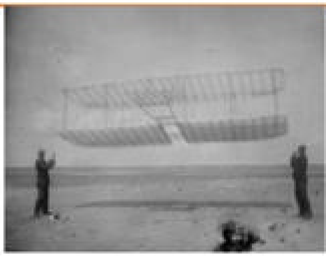
The main milestones that led to the Wright Flyer taking off…

1867
Wilbur is born, with Orville arriving four years later.

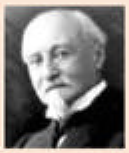
1869
The Wright family move to Dayton, OH, due to the father's work commitments.

1892
Both brothers team up to open a bicycle repair shop. They begin building bikes a few years later.

1900
Years of research lead to the brothers testing the Wright Glider (right), an unpowered biplane with a forward elevator for pitch control.



IN THEIR FOOTSTEPS...



Octave Chanute

While not a protégé of the Wright brothers, Octave Chanute was a key collaborator. A French-born American railway engineer and aviation pioneer, Chanute worked extensively with the brothers and even produced his own gliders, kites and model aircraft. He also wrote a celebrated book on early aircraft: Progress In Flying Machines.

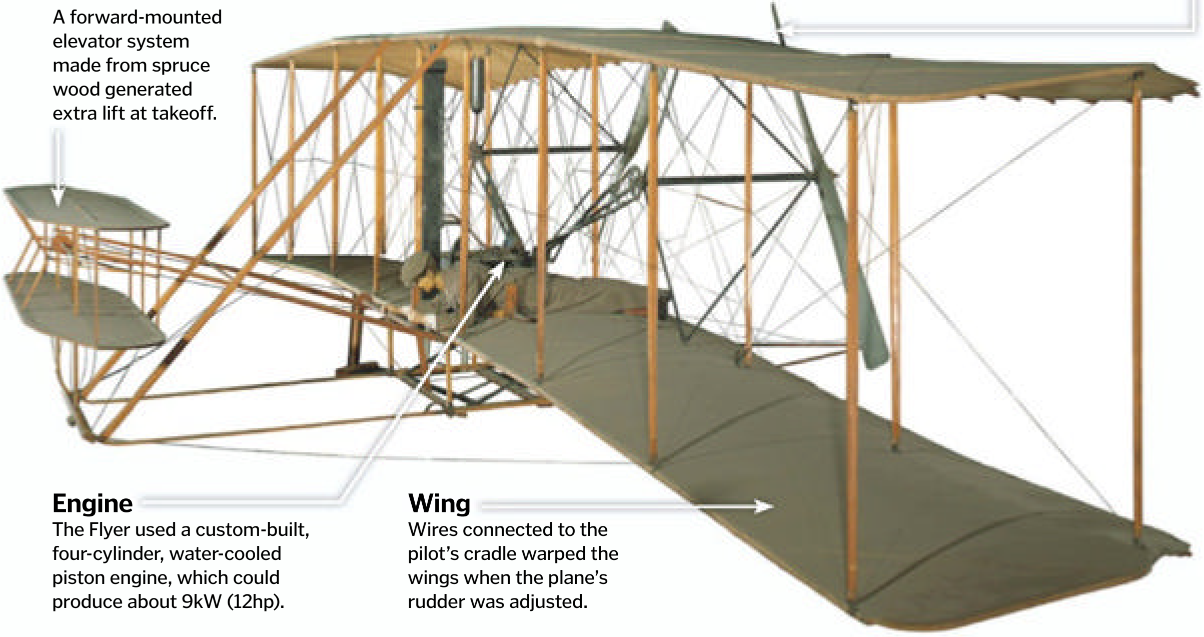
Augustus Herring

This American aviator followed in the Wrights' and Chanute's footsteps by actually flying a compressed air engine biplane glider. In addition, in 1909 Herring set up an aviation company and, despite suffering from a series of strokes, went on to work with the US Army in the design of aircraft used throughout World War I.

DID YOU KNOW? *The brothers tossed a coin to see who would first test the Wright Flyer – Wilbur won the toss*

The Wright Flyer in focus

Take a closer look at the pinnacle of the Wright brothers' aviation careers



Elevator
A forward-mounted elevator system made from spruce wood generated extra lift at takeoff.

Propeller
Two large propellers were driven by a sprocket chain drive, granting the Flyer a small amount of thrust.

Engine
The Flyer used a custom-built, four-cylinder, water-cooled piston engine, which could produce about 9kW (12hp).

Wing
Wires connected to the pilot's cradle warped the wings when the plane's rudder was adjusted.

– who each piloted the glider in turn – racked up almost 1,000 flights between them over a two-month period, covering distances at Kitty Hawk of up to 190 metres (622 feet).

Realising they had cracked both the aerodynamic and control issues that all of their predecessors had struggled with, the two brothers turned their attention to a powerplant for the glider. In 1903 they built their own four-cylinder internal combustion engine and returned to Kitty Hawk to trial it. Unfortunately the first attempt ended in the engine stalling during takeoff and the front of the plane getting damaged, but after a couple of repairs, the second flight ended in resounding success.

Lifting off at 10.35am on 17 December 1903, the Wright Flyer flew 36 metres (120 feet), then 53 metres (175 feet), followed by 60 metres (200 feet) and finally 259.7 metres (852 feet). This series of flights heralded a new era of aviation and propelled the Wright brothers and their aeroplane to worldwide fame.

The Wright Brothers National Memorial is based in the Kill Devil Hills, NC – not far from Kitty Hawk

> "The brothers became well known for their academic and practical application of modern engineering"

Top 5 facts: Wright bros

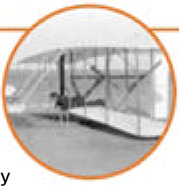
1 No college
Wilbur and Orville were the only members of the Wright family who didn't attend college. Orville spent the years learning the printing trade, while Wilbur helped at the local church.

2 Lifelong bachelors
Neither of the Wright brothers married throughout their lives. Wilbur is recorded as once saying that he "did not have time for both a wife and an airplane."

3 Child's play
In their later lives, the Wright brothers attributed their fascination with flying machines to a small toy helicopter which their father had brought home one day from his travels.

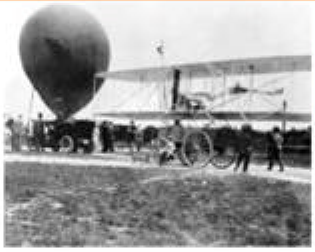
4 Luminaries
Both of the brothers extensively catalogued their aviation experiments, leading to Wilbur Wright delivering a talk at the prestigious Western Society of Engineers in Chicago in 1901. The speech was entitled 'Some Aeronautical Experiments'.

5 Hobby to business
In 1909 the Wright Company was incorporated with Wilbur as president and Orville as one of two vice-presidents.



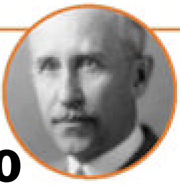
1903
The brothers successfully fly the Wright Flyer in sustained flight at Kitty Hawk, NC. Its fourth flight covers 259.7 metres (852 feet) in just 59 seconds.

1909
The Wright Company sells the first-ever military aircraft, the Wright Military Flyer (right), to the US Army Signal Corps.



1912
Wilbur dies of typhoid fever on 30 May at 45 years old.

1915
Orville ends his leadership of the Wright Company by selling his shares to a group of financiers.



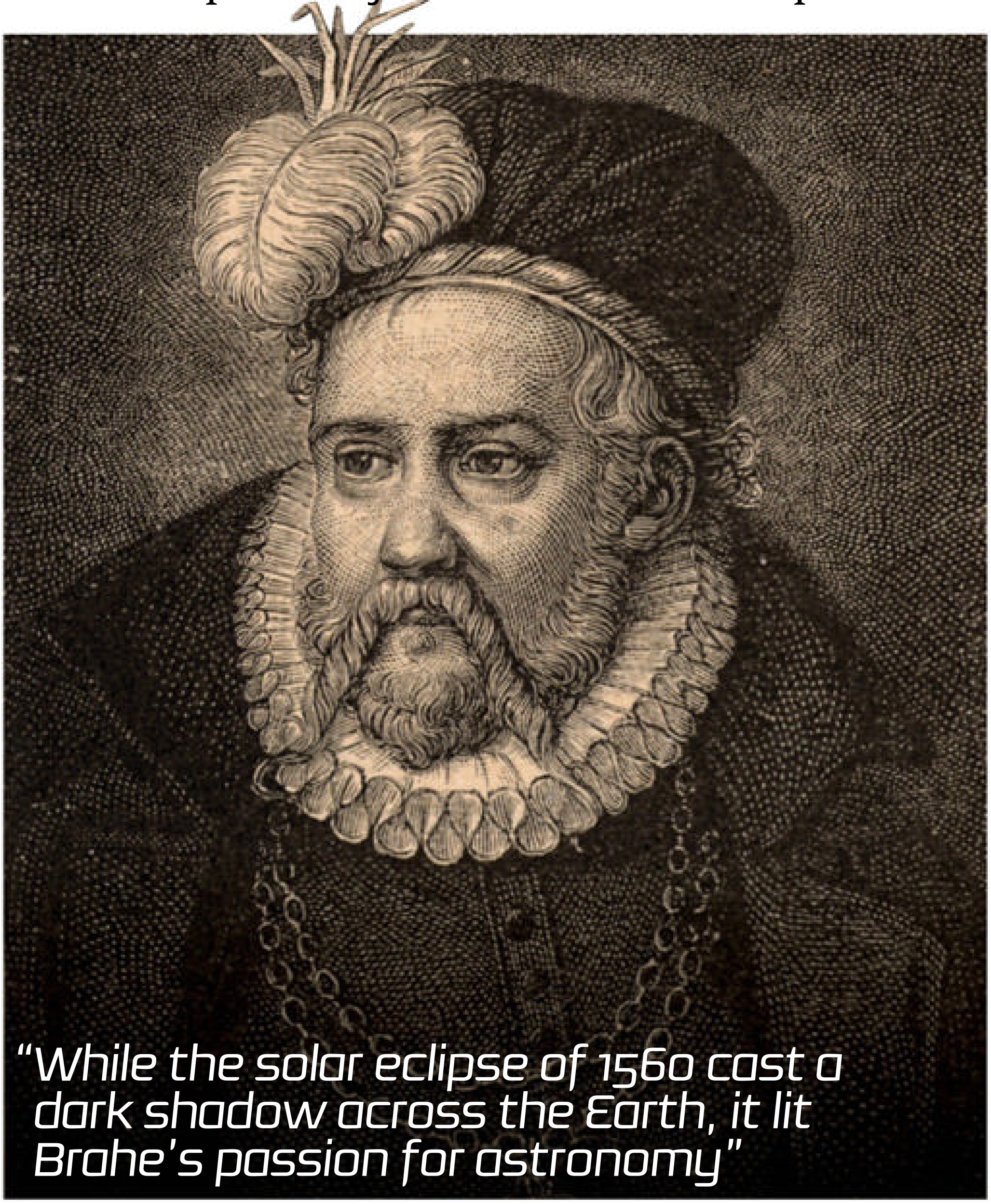
1920
Orville joins the board of the National Advisory Committee for Aeronautics – a precursor to NASA.

1948
Orville suffers a heart attack on 27 January and dies three days later in Dayton, OH, aged 76.

© Thinkstock; Getty

Tycho Brahe

Meet the man who coined the term 'nova' and calculated planetary motion before telescopes

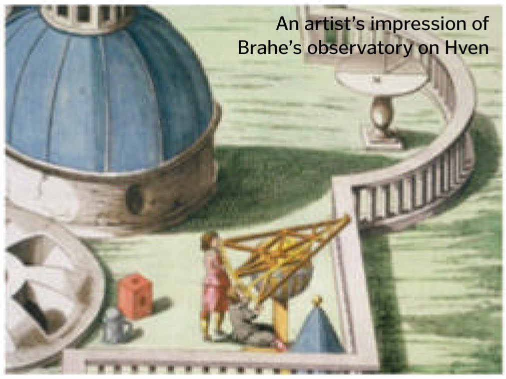


"While the solar eclipse of 1560 cast a dark shadow across the Earth, it lit Brahe's passion for astronomy"

Few other naked-eye astronomers have plotted the movement of planets quite as accurately as Danish nobleman Tycho Brahe. His observations of a new star in 1572 and the Great Comet of 1577 helped to shake off the Aristotelian belief that the planets and stars were unchanging and locked in 'immutable' celestial spheres.

Brahe's schooling began at an early age. Indeed, at just two years old, he was taken from the family home by his uncle to start his education. At age 12, he began studying law at the University of Copenhagen, as was the norm for sons of nobility. However, while the solar eclipse of 1560 cast a dark shadow across the Earth, it lit Brahe's passion for astronomy, and he emerged himself in the works of the great astronomers of the time.

For some time Brahe studied abroad, but upon his return another uncle – Steen Bille – funded the construction of an observatory and chemical laboratory at Herrevad Abbey. It was here in 1572 that he first noticed the appearance of a very bright star. At the time, the popular theory was that the planets and stars were carried on material spheres (spherical shells) that fitted tightly around each other. Brahe's observations proved that his sighting was indeed a new star and not a local phenomenon, and therefore this arrangement was impossible. A year later he published his first book – *De Nova Et Nullius Aevi Memoria Prius Visa Stella* (*On The New And Never Previously Seen Star*) –



An artist's impression of Brahe's observatory on Hven

A life's work

A quick guide to Tycho Brahe's illustrious career as an astronomer

1546
Tycho Brahe is born at Knutstorp Castle in the then-Danish Scania, to nobleman Otte Brahe and his wife Beate Bille.

1559
Brahe begins his studies in law at the University of Copenhagen.

1560
The prediction of a solar eclipse on 21 August 1560 impresses Brahe enormously, and inspires him to study astronomy.

1572
Brahe first observes a new star, now known as SN 1572, from the Herrevad Abbey observatory.

1573
Brahe publishes his book, *De Nova Stella*, coining the term 'nova' for a new star.

IN THEIR FOOTSTEPS…

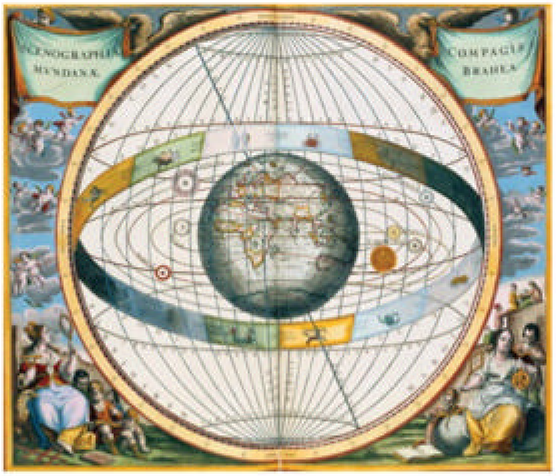
Johannes Kepler

In Prague, Brahe was assisted by Johannes Kepler, a former maths teacher from Germany. The pair came head-to-head after Kepler publicly criticised the Tychonic system. In 1601, Brahe invited him to Prague and was so impressed by his ideas that he made him his successor. Kepler then used Brahe's data to develop his three laws of planetary motion.

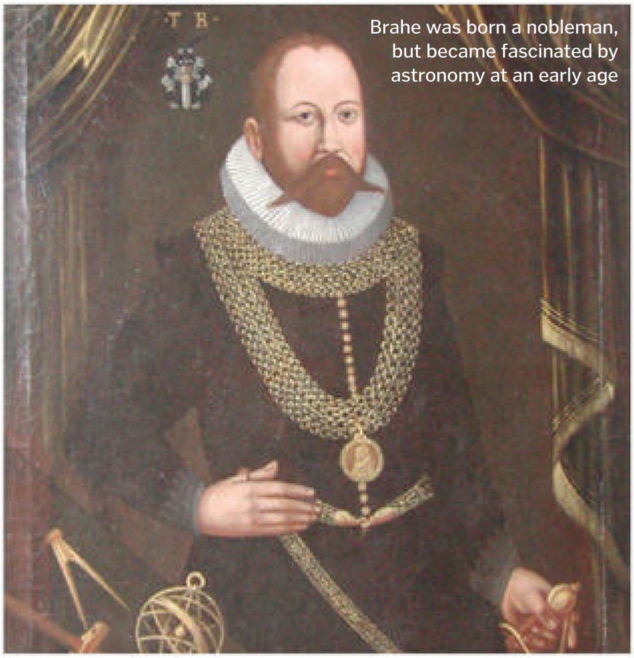
Isaac Newton

Brahe and Kepler's work provided a foundation for Sir Isaac Newton's laws of gravity, presented in 1687, explaining how planets could stay in orbit without being fixed to solid spheres. Gravity also meant that the planets must orbit around the Sun. He also modified Kepler's third law, stating that all the planets and the Sun orbit around a common centre of mass.

DID YOU KNOW? *There is much speculation that Brahe's life and work provided inspiration for Shakespeare's Hamlet*



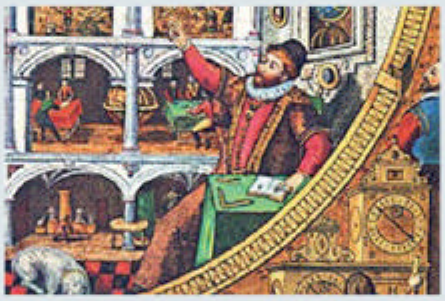
Kepler collaborated with Brahe and continued his work after he died



Brahe was born a nobleman, but became fascinated by astronomy at an early age

The Tychonic system

The Tychonic system is a model of the Solar System developed by Brahe. Unlike Copernicus's heliocentric model (with the Sun at the centre), he believed that Earth was too 'hulking' and 'lazy' to be continuously in motion. Religion also played a part in Brahe's rejection of heliocentrism, and cited the Bible in his work. Instead, he suggested a 'geo-heliocentric' model in which the Earth is at the centre of the universe, with the Sun and Moon orbiting the Earth and the other planets orbiting the Sun.



Top 5 facts: Tycho Brahe

1 Naked eye
Brahe was the last of the major naked-eye astronomers, as it wasn't until seven years after his death that the first telescopes came into use.

2 Hard nosed
At the age of 19, Brahe lost the bridge of his nose in a sword fight with a fellow student. For the rest of his life he wore a metal prosthesis.

3 Tycho the tyrant?
It is rumoured that Brahe led an oppressive regime on the island of Hven, and that he was deeply despised by the people living there.

4 Murder mystery
It was suggested that Brahe had been poisoned, but after being exhumed from his grave in 2010, results indicated that he probably died from a burst bladder or similar.

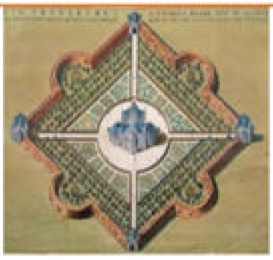
5 Lunar legacy
Craters Tycho on the Moon and Tycho Brahe on Mars are named after Brahe.

and it was from this that the term 'nova' came into common use to describe a new star.

After another tour abroad, King Frederick II, desperate to keep Brahe in Denmark, offered him the island of Hven and funding to set up another observatory. In 1576 Uraniborg was built, and later an underground observatory called Stjerneborg. As well as being observatories, they also functioned as workshops where Brahe designed and built new instruments. He was able to make incredibly accurate observations – they were said to be more accurate than any before.

After King Frederick's death in 1588, Brahe's popularity declined. In 1599, after falling out with King Christian IV, Brahe moved to Prague (then part of Bohemia). Sponsored by Bohemian king Rudolph II, he built a new observatory at Benátky nad Jizerou. Here he was responsible for compiling the Rudolphine Tables – astronomical tables that allowed calculations of the planetary positions for any time in the past or future. Here Brahe's assistant was Johannes Kepler. Brahe entrusted the continuation of his extensive research to Kepler after his death in 1601, who published the finished astronomical tables 26 years later.

1576
King Frederick II of Denmark offers Brahe the island of Hven, where he builds the Uraniborg observatory.



1577
Brahe's observations of the Great Comet (above) prove that objects can move through the celestial spheres.

1599
After a disagreement with the new Danish king Christian IV (right), Brahe moves to Prague, becoming Bohemia's official imperial astronomer.

1601
Brahe suddenly contracts a kidney or bladder ailment and dies 11 days later, aged 54.

© Thinkstock; Alamy; Corbis

Albert Einstein

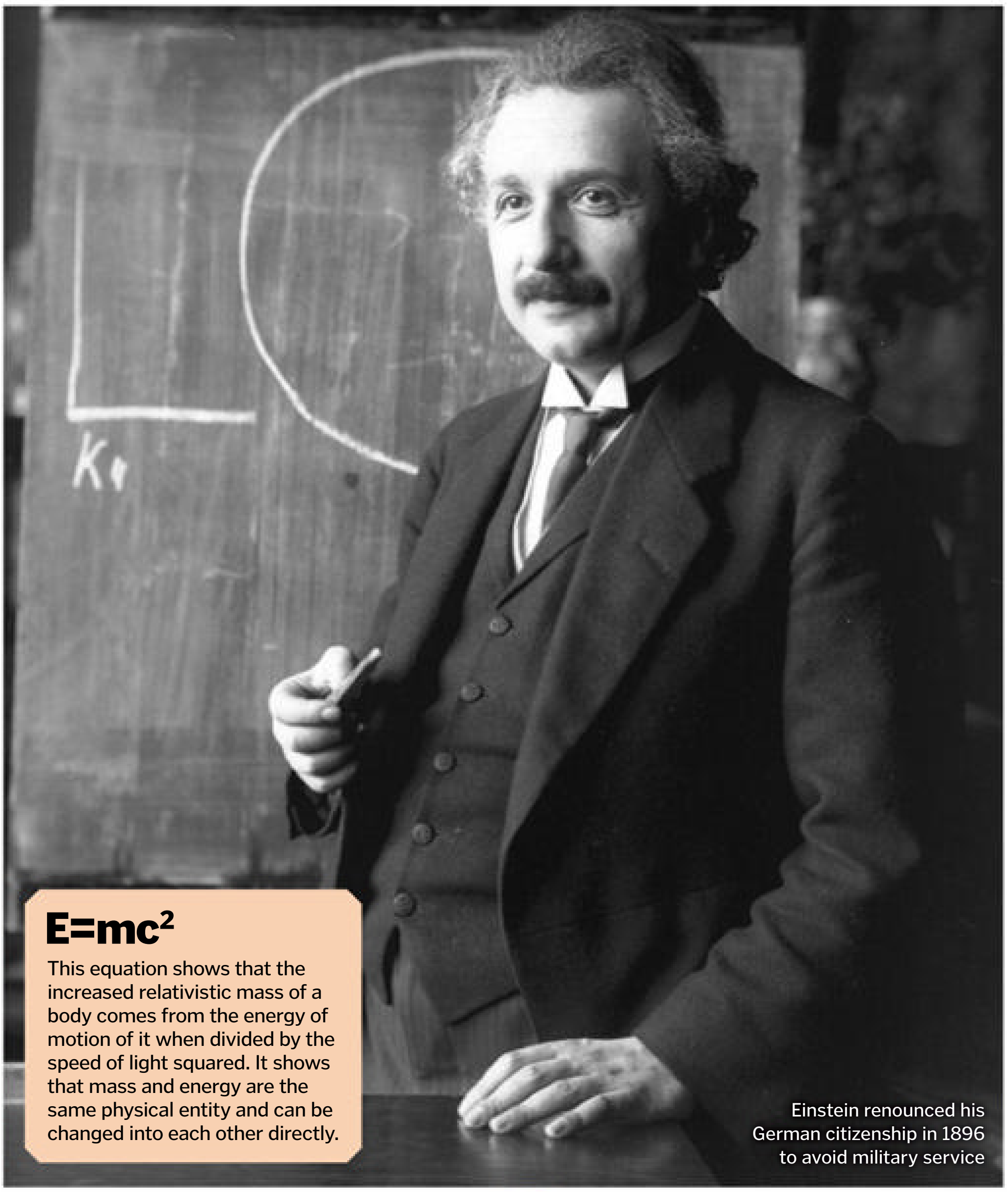
The foremost scientist of his age, Einstein is considered the most influential physicist of all time

Albert Einstein was born on 14 March 1879, in Ulm, Germany. He is considered the most influential physicist of the 20th Century, formulating both the theories of special and general relativity, concepts that still underpin much in the fields of physics and astrophysics today. In 1921 he was awarded the prestigious Nobel Prize in Physics for his explanation of the photoelectric effect – a process where electrically charged particles are released from a substance when exposed to electromagnetic radiation.

Einstein's first real contact with science came when he was a young boy, instigated by his intrigue with his father's compass. Confused by the invisible forces that seemed to be acting upon the needle, he went through his early years fascinated by such forces. Spurred on by reading the work of Aaron Bernstein, which introduced him to the concepts of electricity and light, Einstein dedicated his later teenage years to the nature of light, writing a scientific paper entitled 'The Investigation Of The State Of Aether In Magnetic Fields'.

Despite a great love for the sciences, Einstein had a troubled education. He skipped classes while attending the Swiss Federal Polytechnic School, and his father's failed business led to much disruption, with Einstein having to move frequently. This led to a period where he was forced to take a position at the Swiss patent office in Bern, a role significantly less prestigious than his desired doctorate.

In hindsight, though, the position at the patent office was ideal, as the work left much time for him to theorise on the properties and nature of light. Then, suddenly, in 1905 Einstein made a breakthrough, starting what is now



$E=mc^2$

This equation shows that the increased relativistic mass of a body comes from the energy of motion of it when divided by the speed of light squared. It shows that mass and energy are the same physical entity and can be changed into each other directly.

Einstein renounced his German citizenship in 1896 to avoid military service

A life's work

We chart Einstein's phenomenal journey to becoming the most influential physicist

1879
Einstein is born on 14 March in Ulm, Germany.

1896
After avoiding military service, Einstein enrolled in a four-year mathematics and physics teaching course in Zurich.

1905
Einstein released four papers on the photoelectric effect, Brownian motion, special relativity and the equivalence of matter and energy.

1906
Einstein receives a doctoral degree from the University of Zurich.

1908
He becomes lecturer at the University of Bern.

IN THEIR FOOTSTEPS…

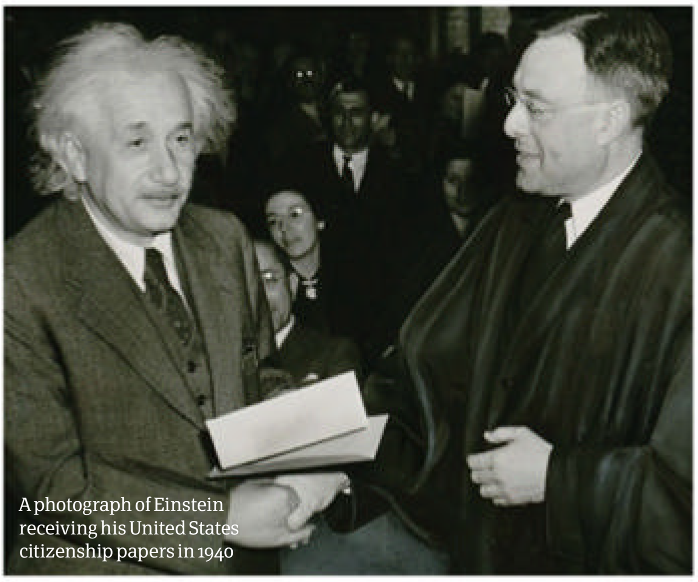
Stephen Hawking

The English theoretical physicist has acknowledged a debt to Einstein. Most famous for his theorems regarding gravitational singularities, Hawking has published many books. In a recent interview with *Time*, when asked what he would ask Einstein if he were alive today, Hawking said: "I would ask him why he didn't believe in black holes."

Carl Sagan

American astrophysicist Carl Sagan was a proponent of the power of science and the importance of Einstein, stating that: "Those afraid of the universe as it really is will prefer the fleeting comforts of superstition. But those with the courage to explore the weave and structure of the cosmos will penetrate its deepest mysteries."

DID YOU KNOW? Einstein had an illegitimate daughter born in 1902



A photograph of Einstein receiving his United States citizenship papers in 1940

Einstein's former summer home in Germany was confiscated by the Nazis and is currently the subject of a legal battle over its ownership

termed his 'miracle year'. In that time he published four papers: the first on the photoelectric effect, the second on the existence of atoms, the third introducing the mathematical theory of special relativity and the fourth on the theory of relativity. Famously, Einstein published the last paper almost as an afterthought, despite it containing the key equation for which he is famous: E=mc2.

At first the scientific establishment ignored Einstein's papers. Fortunately, though, they caught the attention of the foremost scientist of the age: Max Planck, the founder of quantum theory. Through Planck, Einstein became a respected member of the international community, attending the prestigious Solvay conferences and being offered important positions at Europe's foremost universities.

After completing his theory of general relativity in November 1915, Einstein's work was interrupted by World War I. Being a life-long pacifist, Einstein opposed the war and spoke frequently on its folly. After its conclusion, Einstein toured the world, but his period away from Europe was soon to be made permanent, with Einstein fleeing Nazi Germany in 1933. He settled in America and was granted US citizenship in 1940.

While in America, though he was not immediately convinced that an atomic bomb was possible, Einstein had encouraged the US government, including personally writing to President Roosevelt, to research nuclear chain reactions using uranium in response to German advances in the field. He did not work directly on the project to build a bomb, despite it being heavily based on his own work. According to reports, Einstein was on vacation when the first atomic bomb was dropped on Hiroshima, Japan. This action and its aftermath led to him undertaking anti-nuclear campaigns and lectures for the rest of his life.

Einstein's later years saw him pioneer numerous key theories including wormholes, multi-dimensional models and the possibility of time travel, as well as discovering his unified field theory. The latter was to be an all-embracing theory that would unify the forces of the universe and physics into one framework. The theory was never completed, however, with Einstein dying of an aortic aneurysm in 1955.

Top 5 facts: Einstein

1 Boy of few words

According to reports, Einstein seldom spoke as a child and when he did, it was very slowly. Accounts state he did this until he was nine.

2 Point of inspiration

Einstein's interest in science was reportedly sparked by his father's compass. At the age of five he thought there must be some force in the apparently empty space that acted on the needle.

3 Slow to start

Einstein did not receive outstanding grades while at school and when he left could not get a university position. Instead he went to work in the Swiss patent office.

4 Nuclear pacifist

Einstein was a pacifist and while initially supporting the use of atomic weapons as a deterrent, later campaigned for nuclear disarmament and world peace.

5 Man with two brains

After his death in 1955, Einstein's brain was removed for preservation by Thomas Stoltz Harvey in an attempt to discover what made him so intelligent.

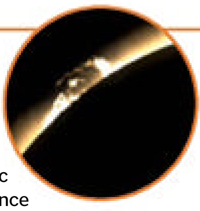
> "In 1905 Einstein made a breakthrough, starting his 'miracle year'"

1911
Einstein moves to Prague, where he acts as professor at the Karl-Ferdinand University.

1912
Einstein moves back to Switzerland, taking up a professorship at his alma mater, the Swiss Federal Institute of Technology in Zurich.

1915
Einstein completes his general theory of relativity.

1919
A solar eclipse provides dramatic observable evidence that his general theory of relativity is correct, making him a worldwide celebrity.



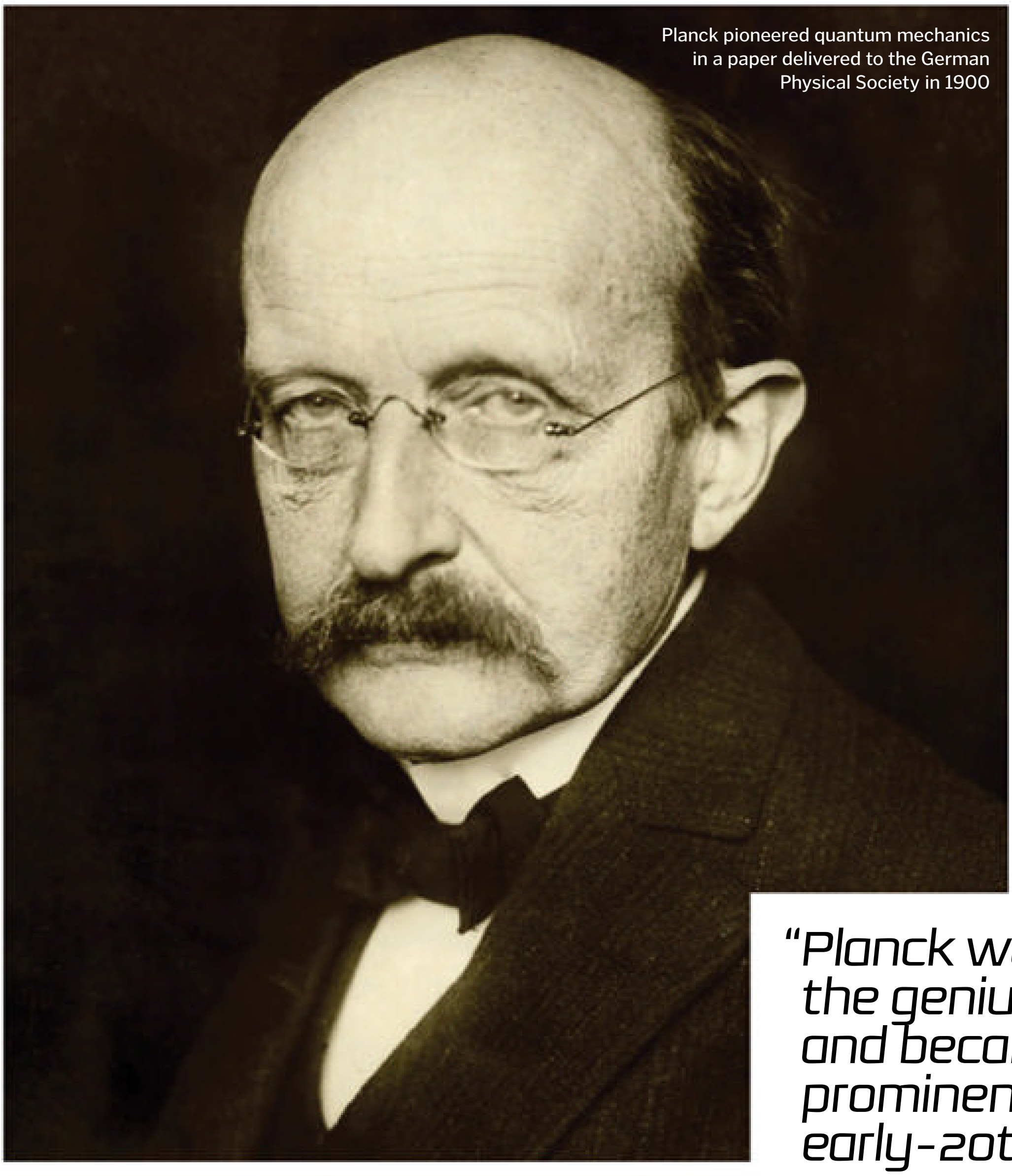
1921
16 years after its publication in 1905, Einstein wins the Nobel Prize in Physics for his work on the photoelectric effect.

1933
Einstein and his family flee from Nazi Germany to settle in the United States. He works at the Institute of Advanced Study at Princeton.

© Roland zh; NASA

Max Planck

The father of quantum physics, Max Planck was one of the foremost theoretical physicists of the 20th century whose work ushered in a new era of science



Planck pioneered quantum mechanics in a paper delivered to the German Physical Society in 1900

If you had to choose two scientists of the 20th century whose work most affected its course and discoveries, the first would no doubt be Albert Einstein, but the second could be Max Planck. Einstein's theory of relativity revolutionised how humans perceived and understood space and time, while theoretical physicist Planck's development of quantum theory, with his probing work into atomic and subatomic processes, radically transformed how physics was understood and directly led to many other discoveries and inventions that still have a widespread impact today.

Easily Max Planck's most important discovery was his realisation that the energy of electromagnetic waves is contained within indivisible 'quanta' packets that have to be radiated or absorbed as a whole. This is commonly referred to as Planck's black-body radiation law and, as can be seen in detail within 'The big idea' boxout explanation, it is both simple and incredibly enlightening. However, when Planck delivered his research for the first time in 1900, it was anything but, with its suggestions seemingly conflicting directly with all of classical physics. Indeed, even Planck himself did not fully believe his law was correct, only reluctantly deducing it through a cold sense of logic.

His remarkable discovery was not recognised either by the existing scientific establishment, with recognition only coming after Einstein himself adopted the idea of quanta and later introduced the follow-on theory of wave-particle duality in 1909. Following this, Planck was suddenly seen as the genius he had always

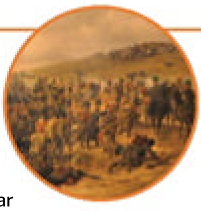
> *"Planck was suddenly seen as the genius he had always been and became one of the most prominent scientists of the early-20th century"*

A life's work

Events that sculpted the life of one of the 20th century's leading physicists

1858
He is born Max Karl Ernst Ludwig Planck in Kiel, the Duchy of Holstein in the German Confederation.

1864
Experiences war first hand as Prussian and Austrian troops march through Kiel during the Second Schleswig War.

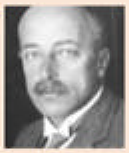


1878
After graduating early from the Maximilians school in Munich, he travels to Berlin to study, passing his exams with flying colours.

1880
Planck presents his habilitation thesis entitled Equilibrium States Of Isotropic Bodies At Different Temperatures and becomes a private lecturer in Munich.

1885
Planck is appointed associate professor of theoretical physics at the University of Kiel.

IN THEIR FOOTSTEPS…



Max von Laue
Max von Laue was a student under Max Planck and later Nobel prize winner, receiving the prestigious award for his discovery of the diffraction of X-rays by crystals. For four decades he was one of the foremost scientists in Germany and spent many years re-organising Germany's broken scientific institutions post-WWII.

Gustav Ludwig Hertz
A German experimental physicist and another Nobel prize winner, Gustav Ludwig Hertz was one of Max Planck's earliest students, later going on to win the prestigious physics accolade for his experiments into inelastic electron collisions in gases. Indeed, Hertz had one of the longest careers of any of Planck's students, dying aged 88 in 1975.

DID YOU KNOW? *The asteroid 1069 was named after Planck as 'Stella Planckia' in 1938*

Max Planck working in his study in 1918 – the year he was awarded the Nobel Prize in Physics

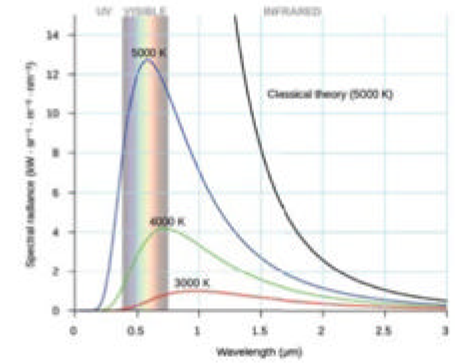
been and became one of the most prominent scientists of the early-20th century, attending among numerous others, the celebrated Solvay Conference in Brussels in 1911.

Indeed, famously it was due to Planck's input at the conference that Henri Poincaré – the most famous mathematical physicist of the 19th century – could provide mathematical proof that Planck's radiation law required the existence of quanta and, as a knock-on effect, converted many of Europe's top scientists to this new quantum theory.

And so quantum theory was born, and over the following decades it was built upon and expanded by some of the most well-known scientists of all time. From Einstein to Niels Bohr, Erwin Schrödinger to Paul Dirac, Planck – as the father of quantum theory – had given them an entirely new way to look at and understand the processes of the physical world – one which they would go on to explore in much more detail through the nuclear age.

The big idea

Planck's law is a mathematical relationship formula created in 1900 by Max Planck to explain the spectral-energy distribution of radiation emitted by an idealised black-body phenomenon. Key was Planck's assumption that sources of radiation are atoms in a state of oscillation and that the vibrational energy of each atomic oscillator may have a series of discrete values but never any fixed value between. This discovery, along with the ground-breaking work of Albert Einstein, led directly to the end of the age of classical physics.



Top 5 facts: Max Planck

1 Name change

Max Planck was born Karl Ernst Ludwig Marx Planck, but by the age of ten he began signing his name as simply 'Max'. He would continue to use this for the rest of his life, largely abandoning his other forenames.

2 Special theory

Max Planck was one of the first physicists to understand the importance of Albert Einstein's theory of relativity, using his influence to promote the young Einstein's seminal work and expand upon it.

3 Manifesto

Max Planck was one of the German scientists who signed the Manifesto of the Ninety-Three, a 1914 proclamation that supported the German military actions in the early period of World War I. He later regretted signing the declaration.

4 Highest authority

After World War I Planck was considered the highest scientific authority in the whole of Germany and consequently held positions at Berlin University, the Prussian Academy of Sciences and the German Physical Society.

5 Resistant

During WWII Planck was one of very few scientists to remain in Nazi-led Germany.

1892
After years of lecturing, Planck is made full professor at the prestigious University of Berlin.

1900
Planck outlines for the first time his famous black-body radiation law to the German Physical Society.

1918
Max Planck receives the Nobel Prize in Physics for his groundbreaking work on quantum theory.

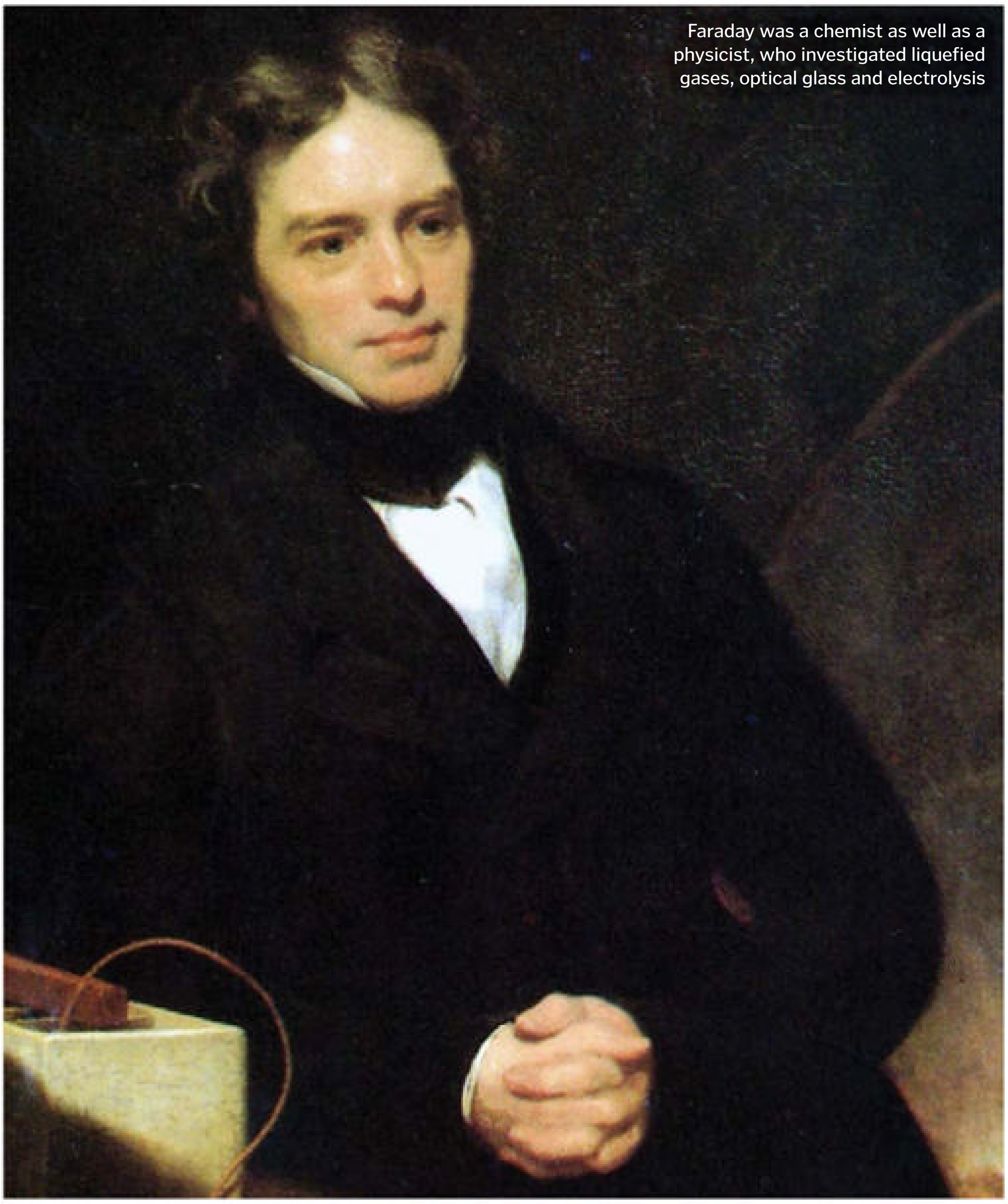
1928
The German Physical Society creates the Max Planck medal and enshrines it as the highest accolade that they can bestow.

1947
Max dies at the age of 89 in his last home situated in Göttingen, Germany.

© Corbis

Michael Faraday

The scientist behind electromagnetic induction who played a key role in inspiring Einstein…


Faraday was a chemist as well as a physicist, who investigated liquefied gases, optical glass and electrolysis

Michael Faraday was born in 1791 to a poor family who couldn't afford to educate him. Few could have guessed that he would go on to massively advance our understanding of electricity and more. He learned to read and write at Sunday school, and became a bookbinder's apprentice in his teens.

Faraday loved to read and he worked his way through the books that he was binding, developing a keen interest in chemistry, electricity and magnetism. His newfound interest in science led him to attend a series of four lectures by chemist Humphry Davy, where he took extensive notes in the hope of securing employment at the Royal Institution. Eventually, his persistence paid off and he managed to get a job working as a laboratory assistant to Professor Davy.

Faraday worked for Davy for several years, during which time the pair travelled to Europe. While with Davy, Faraday made several discoveries in the field of chemistry, including identification of the ring-shaped hydrocarbon benzene. He also made two new chemical compounds: hexachloroethane, which now forms the basis of military smoke grenades, and tetrachloroethylene, which is widely used to dry-clean clothes even to this day.

Faraday's major breakthroughs were not in chemistry though but in physics. In 1820, Hans Christian Oersted discovered that an electrical current could produce a magnetic field. Faraday was convinced that the opposite must also be true, and began his most influential work on electromagnetic induction. His first discovery came shortly after, when he showed that by wrapping two insulated coils of wire around an iron ring a current could be transferred from one coil to another in a process known as mutual inductance.

Keen to further this research, Faraday continued investigating the electromagnetic properties of materials, and this led to his greatest achievement of all in 1831 – the discovery of electromagnetic induction (see 'The big idea' for more information).

A life's work

We highlight some key events from Faraday's electrifying career in the 19th century

1791
Michael Faraday is born in Surrey, UK, to James Faraday and Margaret Hastwell.

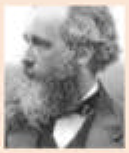
1805
Faraday starts work as a bookbinder's apprentice. During this time he develops an interest in science.

1813
He works as assistant to Professor Humphry Davy, making several advances in the field.

1821
Faraday discovers the principle behind the electric motor, using the idea of electromagnetic rotation.

1824
He is elected a fellow of the Royal Society.

IN THEIR FOOTSTEPS…



James Clerk Maxwell

James Clerk Maxwell was a Scottish physicist best known for his work on electricity, magnetism and optics. His theories on electromagnetism are underpinned by Faraday's experimental work. Maxwell attended many lectures at the Royal Institution and met Faraday on several occasions. He was more mathematically minded than his colleague.

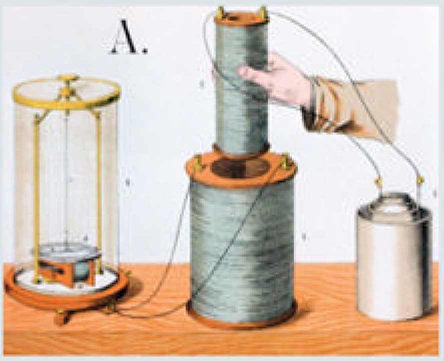
Albert Einstein

The work of both Faraday and Maxwell inspired Einstein, and he kept pictures of both scientists on the wall of his study, alongside an image of Isaac Newton. Einstein's major work was to reconcile Newton's classical laws of physics with the new laws of electromagnetism, pioneered by scientists by the work of Faraday and Maxwell.

DID YOU KNOW? *Due to family money contstraints Faraday left school at the age of 13 to earn money*

The big idea

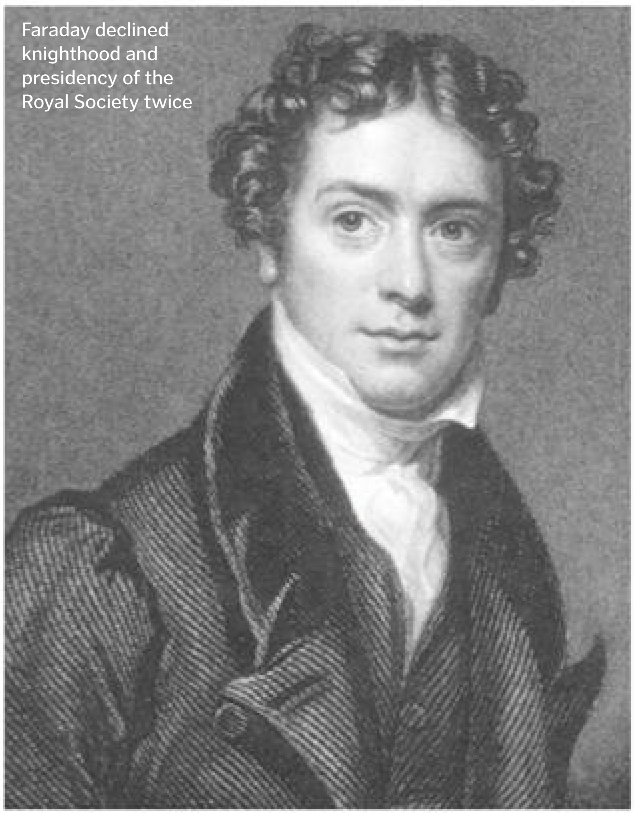
Faraday was a prolific scientist, but is best known for his work on electromagnetic induction. Faraday's Law states that a change in the magnetic environment near to a coil of wire will induce a voltage in the coil. Faraday developed a spinning copper disc, which rotates next to a static magnetic field (provided by a bar magnet). As the disc spins through the magnetic field, a potential difference is generated between the centre and the edge of the disc, creating a steady direct current. Faraday's disc was inefficient, but it provided the basis for the development of transformers, inductors, electrical motors and generators.



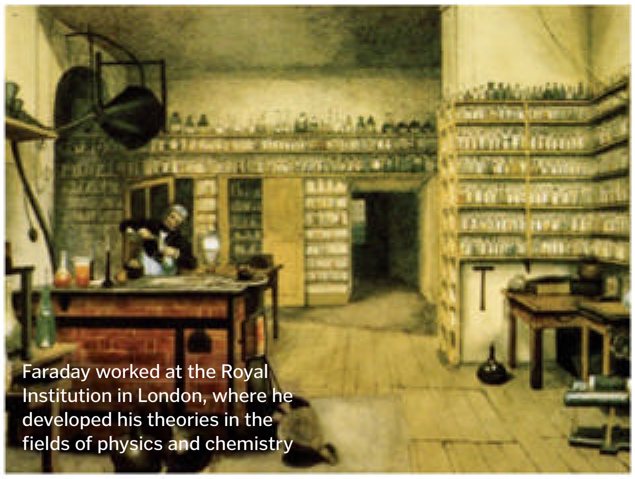
Faraday's work on electromagnetism sparked the interest of other scientists and mathematicians, which led to William Thomson writing to him, suggesting that it was mathematically possible for magnets to alter the plane of polarised light. Faraday had been interested in this idea himself for a very long time, conducting experiments to show how light and magnetic fields interact with each other. This was one of the first steps towards the realisation that visible light is actually electromagnetic radiation.

Later in life Faraday's health declined, but he continued to lecture at the Royal Institution. His scientific contributions were acknowledged by the royal family and, in 1858, Faraday moved to a home in Hampton Court, granted to him by Queen Victoria. He died in 1867 and, having previously refused a burial site at Westminster Abbey, he was buried in Highgate Cemetery.

> *"Faraday worked his way through the books that he was binding, gaining interest in chemistry, electricity and magnetism"*



Faraday declined knighthood and presidency of the Royal Society twice



Faraday worked at the Royal Institution in London, where he developed his theories in the fields of physics and chemistry

Top 5 facts: Michael Faraday

1 No one-trick pony
Faraday developed an early version of the Bunsen burner and also discovered the laws of electrolysis.

2 Nanoparticles
Faraday was the first to report nanoparticles' properties, noticing that gold colloids (sub-micrometre-sized gold particles dispersed in a liquid) have different properties to solid gold.

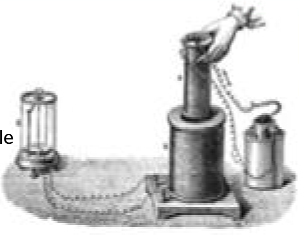
3 Modest man
He declined a knighthood offered by Queen Victoria, and refused to accept presidency of the Royal Society twice.

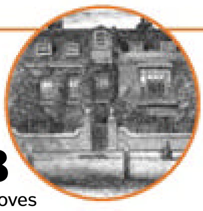
4 Christmas Lectures
Faraday founded the Royal Institution's (RI) Christmas Lectures. To this day, fun science demonstrations for children are broadcast every Christmas in the UK by the RI.

5 Competition
Italian priest Francesco Zantedeschi and US scientist Joseph Henry were working on electromagnetic induction too. Which man came up with the idea first is still contested.

1825
Faraday is appointed director of the laboratory at the Royal Institution, beginning the Christmas Lecture series.

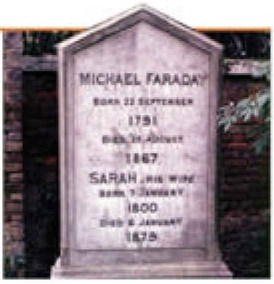
1831
He discovers the principle of electromagnetic induction and invents the electromagnetic generator.





1858
Faraday moves to Hampton Court, awarded to him by Queen Victoria for his services to science.

1867
Faraday dies, aged 75, at his home in Hampton Court. He is buried in Highgate Cemetery.



© Corbis

Alfred Nobel

After exploding into the history books, this Swede sought to leave an academic legacy

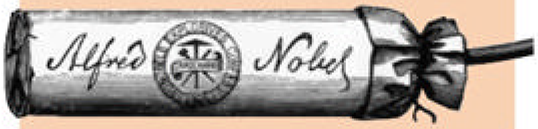
Few scientists have left a legacy more noble than Alfred Nobel. This Swedish chemist not only invented dynamite, but also urged other scientists to explore new avenues of study by establishing the world's most prestigious accolade for intellectual achievement: the Nobel prize.

Since the award was founded in 1901, the greatest minds have been rewarded for their services to the advancement of science and other arts. This peer-assessed award, Nobel hoped, would inspire people to push the boundaries for the benefit of humanity. Past winners include such geniuses as Albert Einstein, Marie Curie and Alexander Fleming.

The big idea

Nobel's work with nitroglycerin led him to experiment with different additives to stabilise the oily liquid. One of Nobel's early 'big ideas' was the invention of a functioning detonator, which he designed first as a simple wooden plug and developed into the patented blasting cap, which was fitted with a small primary charge that could be detonated by a strong shock. While the detonators were groundbreaking, it was Alfred's chemistry that really put him on the map.

To make nitroglycerin safer, Nobel spent years developing the formula; several labs and factories were blown up in the process! Before long he discovered that by adding a very fine inert silica powder called diatomaceous earth, or kieselguhr, the oily nitroglycerin liquid could be transformed into a safer, malleable paste. When shaped into rods, this paste could be inserted into drilling holes and detonated in order to blast rock for mining. And the name of this material? Dynamite.



Nobel was also interested in other aspects of chemistry, including the manufacture of synthetic rubber, leather, artificial silk and more

Alfred Bernhard Nobel was born in Stockholm, Sweden, on 21 October 1833 to Immanuel and Andriette. His mechanical engineer father enjoyed varying degrees of success with a number of inventing and manufacturing business ventures. In 1837, however, Immanuel left in search of better fortune in Russia. By 1842 he had established a profitable business producing equipment for the Russian military, and so the rest of the Nobel family moved out to join him.

Together with his three brothers – Robert, Ludwig and Emil – Alfred was home-educated by private tutors. Taking a cue from his entrepreneurial father, who also designed and made mines, Alfred developed a talent for chemistry – and explosives in particular. In 1850 Alfred travelled to Paris to study chemistry under French professor Théophile-Jules Pelouze, who had been carrying out experiments using concentrated nitric acid to develop explosive materials in his laboratory.

On his return to Russia Nobel began working in his father's factory manufacturing military equipment for the Crimean War. Once the conflict was over in 1856, however, the company struggled to turn a profit and, by 1859, the firm had gone bust, forcing the Nobels to return to Sweden. Alfred's two elder brothers, Robert and Ludwig, remained in Russia with hopes of salvaging what was left of the business.

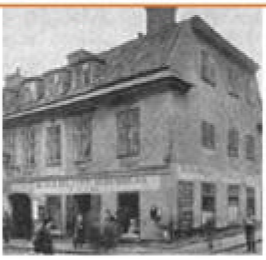
Alfred, meanwhile, started experimenting with explosives in his father's lab. By 1862 he had set up a small factory in which he began to manufacture an exciting but highly volatile explosive called nitroglycerin, which had recently been invented by another of Pelouze's students: Ascanio Sobrero. While Nobel recognised the industrial potential of this explosive, the use of nitroglycerin was just not practical due to its unstable nature. The challenge was to find a way to control nitroglycerin so it could be safely handled.

Nobel spent many years perfecting the formula for his explosives, as well as inventing and developing detonation devices. Eventually his research led him to discover a way to make nitroglycerin stable and practical for the construction and mining industries. This development was the invention of dynamite (see 'The big idea' boxout), for which Nobel obtained the patent in 1867. With a commercial product on his hands, Nobel became a wealthy man at the heart of a brand-new industry. He established some 16 factories

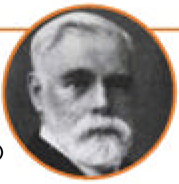
A life's work

The explosive timeline of the inventor of dynamite

1833
Alfred Bernhard Nobel is born in Stockholm, Sweden, on 21 October.

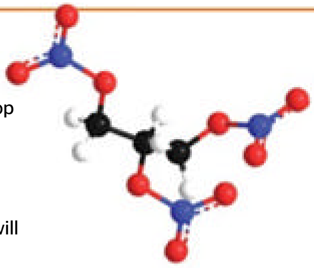


1837
Nobel's father (right) moves away from the family to Finland and then St Petersburg to start up a mechanical workshop. The business goes bankrupt in 1856.



1850
After being reunited with his father in Russia, Nobel travels to France. In Paris he is employed in the laboratory of chemist TJ Pelouze.

1862
In a quest to develop new products for his father's shop, Nobel embarks on the research into nitroglycerin that will lead to dynamite.



5 TOP FACTS ALFRED NOBEL

Factory tragedy
1 In 1864, two years after the invention of Nobel's first detonator, in an unrelated incident, his younger brother, Emil, was killed when one of Nobel's factories exploded.

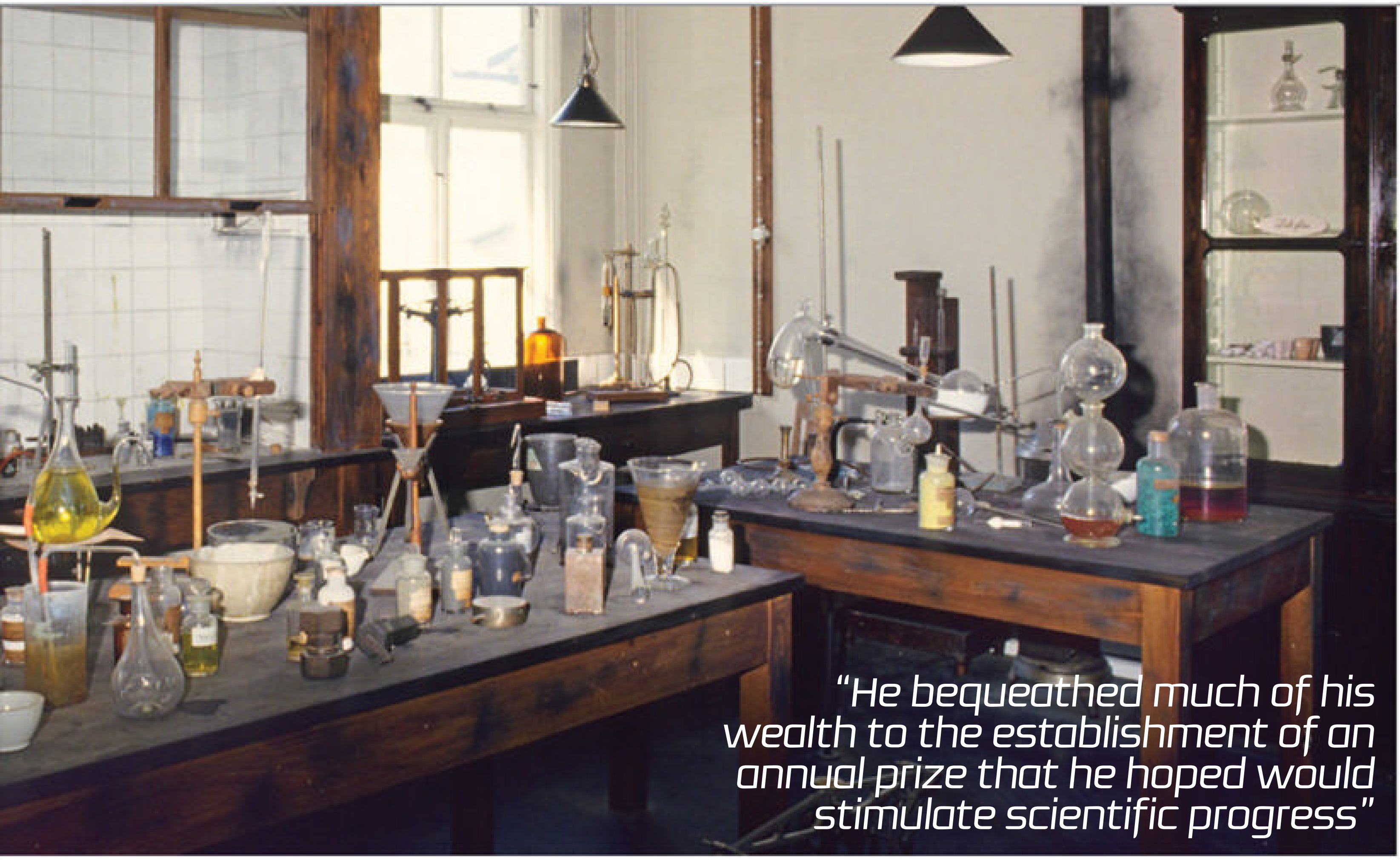
Lived to work
2 Alfred was a workaholic and never married nor had children. At one point he did place a newspaper advert seeking a secretary and household supervisor.

The richest hobo
3 Upon his death it was realised that Nobel had not been registered as a resident of any country, earning him the nickname 'the richest vagabond in Europe'.

Controversial will
4 The Royal Swedish Academy of Sciences claimed there were insufficient instructions in Nobel's will about awarding the prizes.

Dynamite diamonds
5 Organisations like the South African De Beers diamond-mining company were inspired to find use dynamite for blasting rock in its mines.

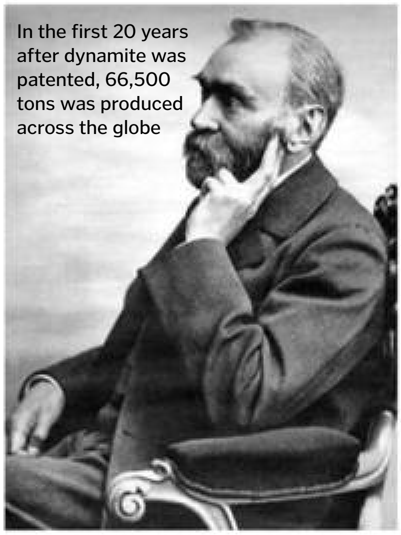
DID YOU KNOW? As a child, Alfred became fluent in English, French, German and Russian, as well as his native Swedish



"He bequeathed much of his wealth to the establishment of an annual prize that he hoped would stimulate scientific progress"

for producing explosives in almost as many countries.

Nobel died aged 63 at his home in San Remo, Italy. Without the help of a lawyer, a year before his death Nobel had signed his last will and testament. In it he passed much of his wealth to the establishment of an annual prize that he hoped would stimulate scientific progress. He wrote: 'The whole of my remaining realisable estate shall be dealt with in the following way: the capital, invested in safe securities by my executors, shall constitute a fund, the interest on which shall be annually distributed in the form of prizes to those who, during the preceding year, shall have conferred the greatest benefit on mankind.'



In the first 20 years after dynamite was patented, 66,500 tons was produced across the globe

In their footsteps…

Ragnar Sohlman

Swedish chemical engineer Ragnar Sohlman became Nobel's personal assistant when he moved to San Remo in 1883. Together with civil engineer Rudolf Lilljequist, Sohlman was appointed executor of Nobel's will. He fought both family and awarding bodies contesting the will to ensure the Nobel prize was set up. Sohlman was also creator of the Nobel Foundation and became its executive director from 1929-1946.

Albert Einstein

Without a doubt one of the most renowned Nobel laureates since the award was set up is Albert Einstein, who received the Nobel Prize in Physics in 1921. In 1905 he had published four pioneering papers: on the photoelectric effect, Brownian motion, the special theory of relativity and equivalence of matter and energy ($E=mc^2$). Einstein famously commented on the irony that a man credited with developing devastating explosives used to wage war had created a prize for peace.

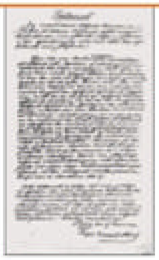
1863
Nobel patents nitroglycerin (a volatile blasting oil) for use as an industrial explosive as well as a blasting cap detonator to set off explosions.

1864
Nobel's brother Emil dies while carrying out nitroglycerin experiments.

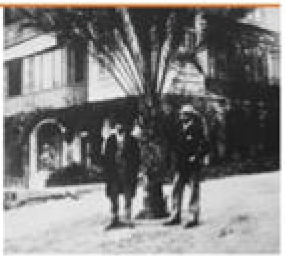
1866
Keen to make handling nitroglycerin safer, Nobel finds the oil can be stabilised by adding diatomaceous earth – and dynamite is born.

1871
After being granted a patent for dynamite in 1867, Nobel sets up the British Dynamite Company (later renamed Nobel's Explosives Company).

1895
Nobel's last will is signed at the Swedish-Norwegian Club in Paris.



1896
Nobel dies at home in San Remo, Italy, on 10 December.



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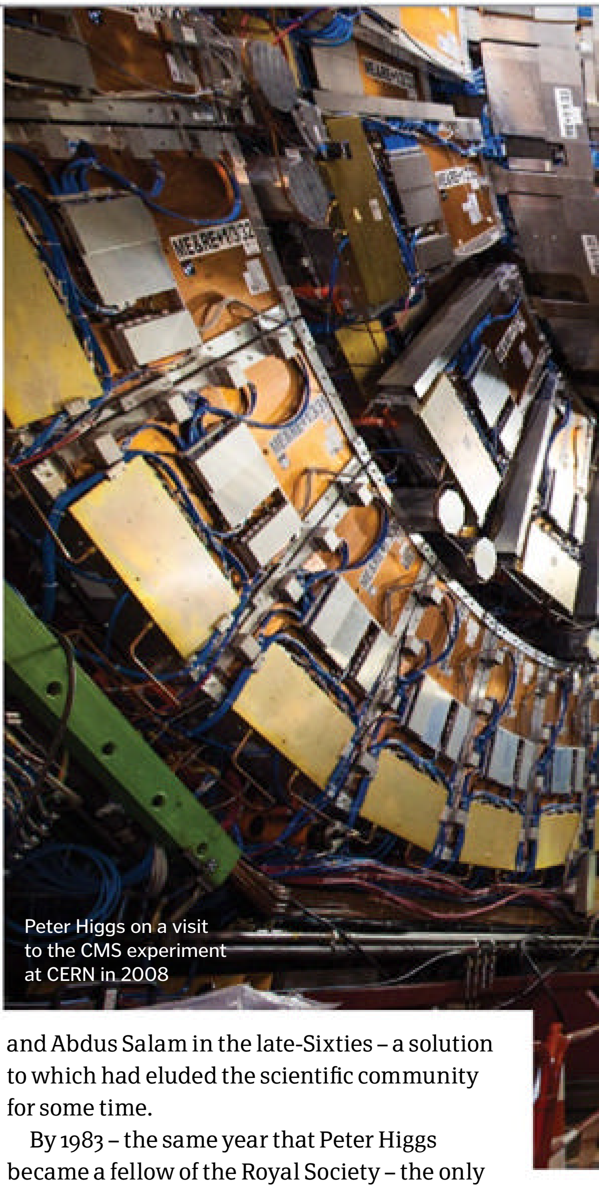
Peter Higgs

Well known in the scientific community for decades, it's only with the suspected discovery of the Higgs boson in 2012 that this physicist shot into the limelight


Peter Higgs on a visit to the CMS experiment at CERN in 2008

We can safely say that the 4 July 2012 discovery of a new particle, likely to be the elusive Higgs boson, had to be the biggest scientific announcement of the year. For most, it was enough to know that the Large Hadron Collider (LHC) – that huge, super-expensive particle accelerator in Switzerland – had given real weight to some decades-old but cohesive physical theory. Some impressive figures were released, then impossible speeds and inconceivably small theoretical particles existing for infinitely short expanses of time were mentioned, and our collective imaginations were captured. For its namesake Peter Higgs though, it must have felt like the ultimate validation of his entire career.

Higgs was born in Newcastle-upon-Tyne, UK, in 1929. He graduated from King's College in the University of London with a first-class degree in Physics then went on to secure a Master's and finally a doctorate in 1954. It was during his work as a research fellow and a lecturer that Higgs began the basis of a paper that would help describe the very nature of mass, even if it was completely disregarded at first. Higgs' work began in quantum field theory – the surreal world of the forces that bind subatomic particles and an exciting new area at the time.

His first paper on the Goldstone boson was picked up and published by a physics journal edited at the only recently founded CERN in Switzerland that same year. To his dismay though, his next paper – finished in 1964 – was rejected on the basis that it bore no relevance to physics. This paper described the radical concept of what became known as the Higgs mechanism, a scalar field present in all points of space, which gives particles mass. The Higgs mechanism was independently discovered by several other leading physicists in the same year, however none of them made any mention of a massive boson, which Higgs had gone on to include in a revision of the same paper.

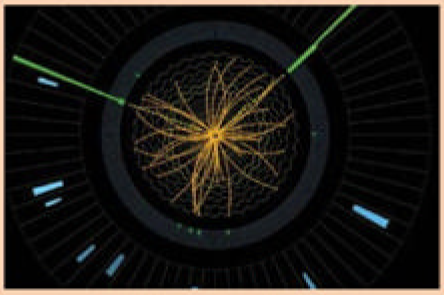
Higgs' ideas were used to describe the origins of particle mass by physicists Steven Weinberg and Abdus Salam in the late-Sixties – a solution to which had eluded the scientific community for some time.

By 1983 – the same year that Peter Higgs became a fellow of the Royal Society – the only unproven parts of this electroweak theory were the Higgs field and the Higgs boson, but it took nearly 20 years and physical experiments of an unprecedented scale in the LHC and beyond, to finally draw a line under the Higgs boson.

Peter Higgs retired in 1996 from a career that also saw him win the Rutherford Medal and the Dirac Medal. In the wake of 2012's CERN announcement, he has received praise from many notable peers – including Stephen Hawking, who has publicly recommended him for the Nobel Prize in Physics. ◆

The big idea

The existence of the Higgs boson hasn't been proven absolutely, but CERN's experiments did confirm the existence of a new particle that is consistent with Higgs' theory. For most physicists, there's no doubt it's the Higgs boson. What this particle proves is the existence of the Higgs field, which allows the building blocks of our universe to gain mass and form stars, planets, galaxies and everything around us. Currently, it provides the answers to the last few burning questions in the Standard Model of Physics, and in the future it could prove integral to science.

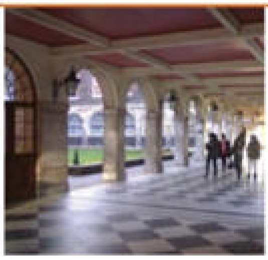


A life's work

The big events that led to the discovery of this tiny particle

1929
Born on 29 May, the family moves around a lot as Higgs' father is a sound engineer for the BBC.

1954
Finishes his PhD at King's College London (right) and goes on to lecture at the University of Edinburgh.



1964
He describes the Higgs mechanism in a paper, which is rejected. He later revises it to include the Higgs boson.

1983
W and Z bosons are discovered, leaving only the Higgs particle to confirm the electroweak theory. Higgs also enters the Royal Society.

1991
Higgs becomes a fellow at the prestigious Institute of Physics, London.

5 TOP FACTS
PETER HIGGS

High five

1 Physicists use standard deviation to determine an official discovery or not. At 5 sigma, there's a one in 3.5 million chance the Higgs boson data is a fluke.

The 'God particle'

2 The Higgs boson has been nicknamed the 'God particle', attributed to physicist Leon Lederman, whose book originally referred to it as the 'goddamn particle'.

Need for speed

3 Two of the highest-energy particle accelerators in the world were employed to search for the Higgs boson – the LHC, and the Fermilab's Tevatron, near Chicago, IL.

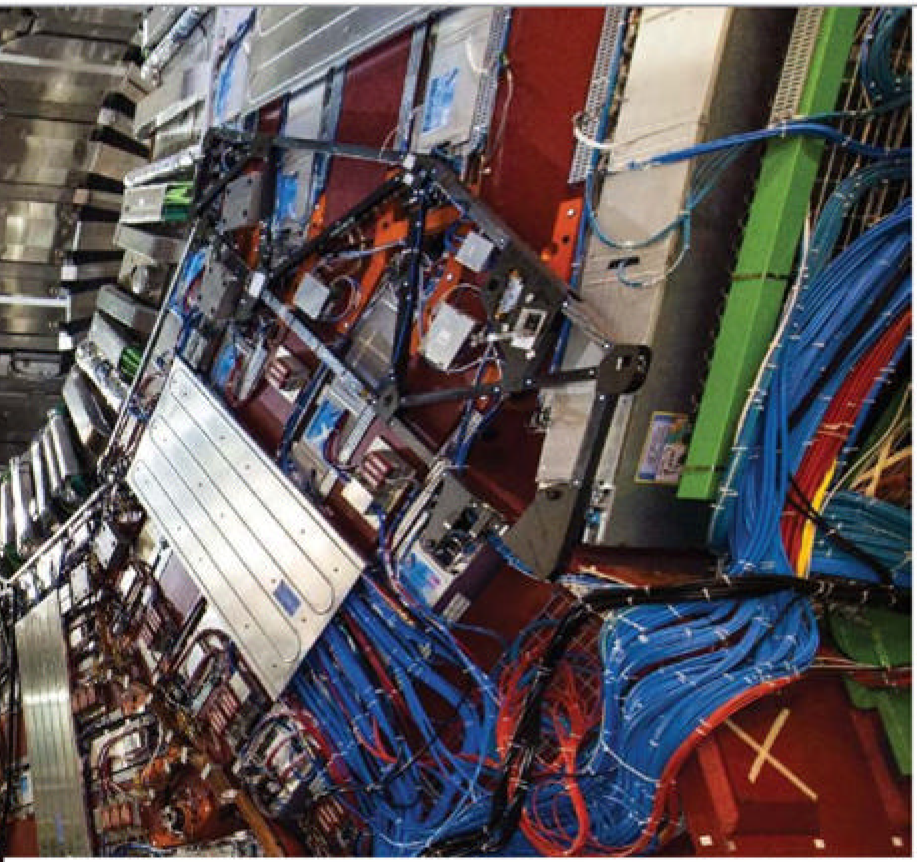
Big Bang

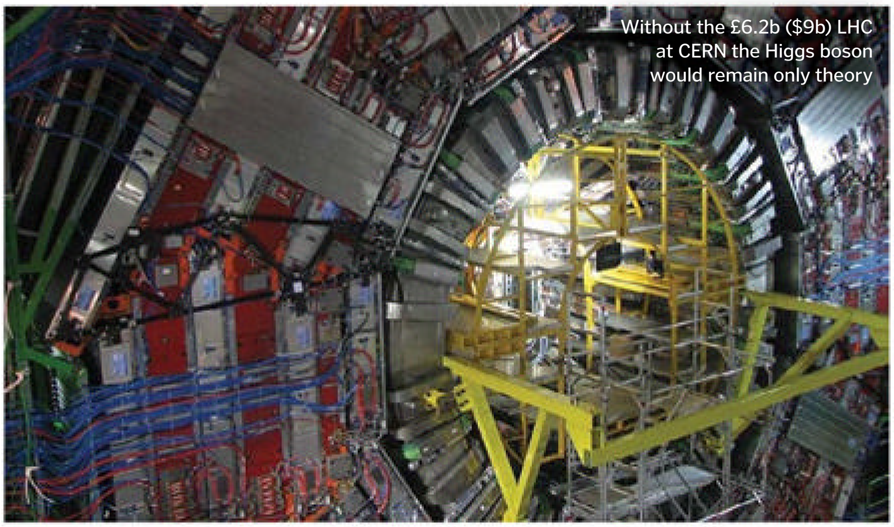
4 Conditions conducive to the creation of the Higgs boson were created by smashing elementary particles together at nearly the speed of light.

Humble Hawking

5 Many who doubted the existence of the Higgs boson, including Professor Stephen Hawking, who bet Gordon Kane $100 that CERN would find nothing.

DID YOU KNOW? *Reacting to the discovery, Higgs said "It's very nice to be right sometimes"*





Without the £6.2b ($9b) LHC at CERN the Higgs boson would remain only theory

In their footsteps...

Ken Currie

The celebrated Scottish artist Ken Currie was commissioned by the University of Edinburgh to paint a portrait of Peter Higgs in 2008. He admitted to being inspired by Higgs' work – not claiming to understand his theory, per se, but grasping the sublime and 'beautiful' nature of his solution.

Sir David Wallace

Higgs was Wallace's advisor while he was studying a PhD in elementary particle theory. Formerly a researcher at Princeton University and a lecturer at Southampton University, it's for his work as director of the Edinburgh Parallel Computing Centre that he was awarded a CBE.

> *"During his work as a lecturer Higgs began the basis of a paper that would help describe the very nature of mass"*

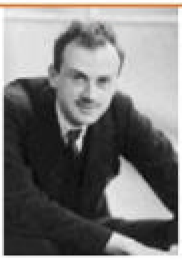
THE UNIVERSITY OF EDINBURGH

1996

Higgs retires and becomes emeritus professor at the University of Edinburgh.

1997

He receives an award for his work in theoretical physics, named after a hero of his: theoretical physicist Paul Dirac (right).



2004

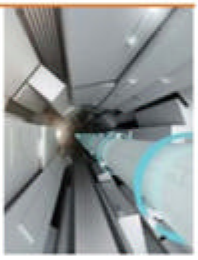
Another award – this time the Israeli Wolf Prize in Physics, though Higgs refuses to fly to Jerusalem to receive it on moral grounds.

2011

The results of CERN's initial experiments with the LHC in December are extremely positive, but more tests are needed to be certain.

2012

The strongest indication of a new particle with significant mass is announced by CERN in July. For his work, Higgs is made a Companion of Honour at the start of 2013.



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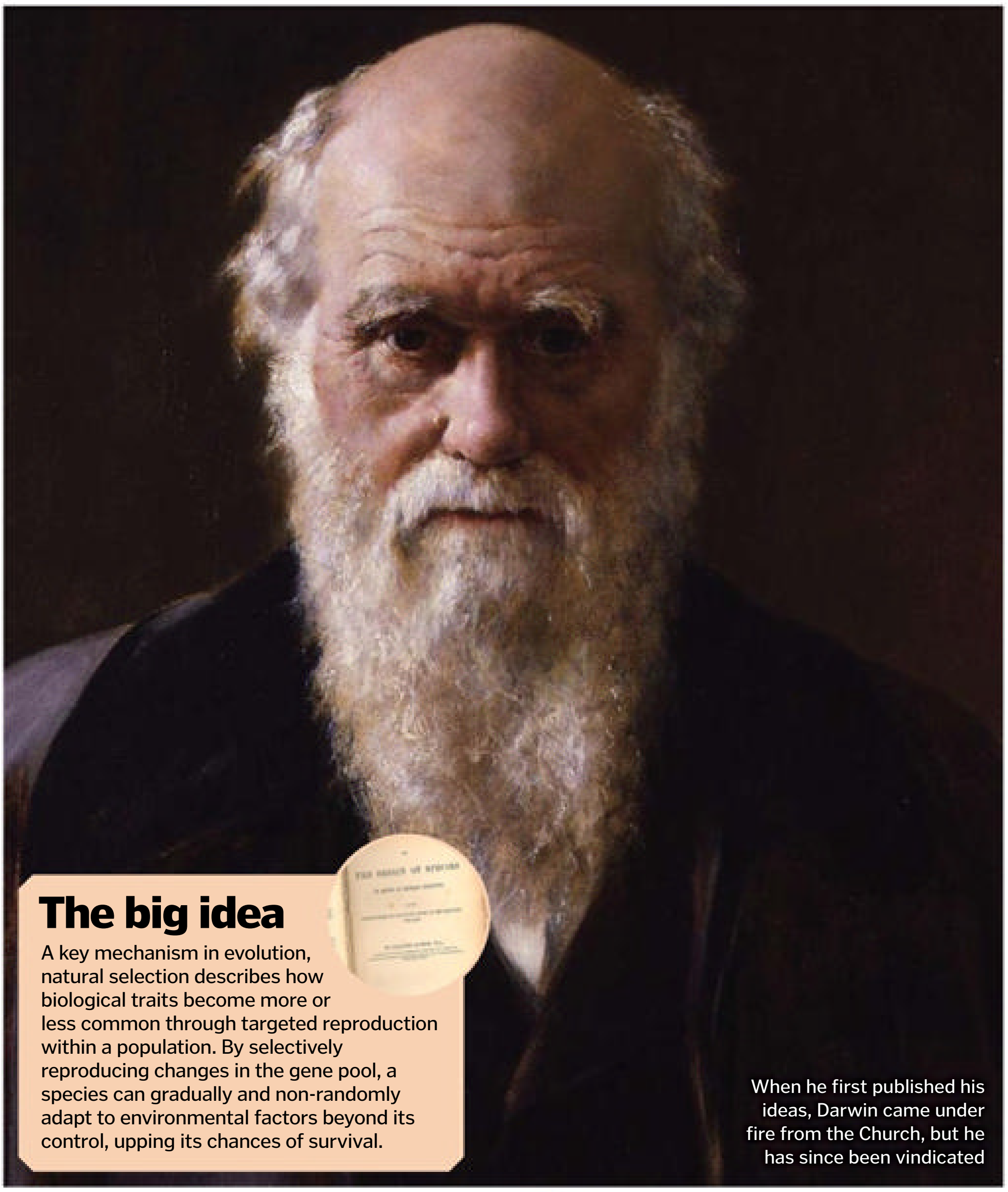
Charles Darwin

The father of evolutionary biology, Darwin is the most famous naturalist of the Victorian era, if not all time



When he first published his ideas, Darwin came under fire from the Church, but he has since been vindicated

The big idea

A key mechanism in evolution, natural selection describes how biological traits become more or less common through targeted reproduction within a population. By selectively reproducing changes in the gene pool, a species can gradually and non-randomly adapt to environmental factors beyond its control, upping its chances of survival.

Charles Robert Darwin was an English naturalist renowned today for his theories of evolution and natural selection, both of which were introduced in his seminal work *On The Origin Of Species*. The book was both lambasted and celebrated on its publication. Early controversy stemmed from its apparent undermining of religious scripture, but it would become one of the most influential works of Western society, with the entire field of evolutionary studies arising from it.

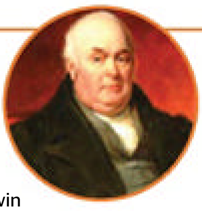
Though *On The Origin Of Species* was published in 1859, Darwin originally conceived of evolution by natural selection shortly after an around-the-world tour starting in 1831. He embarked on the journey to expand his newly formed interest in natural history, spending the trip collecting specimens and analysing many interesting species, when not suffering from seasickness. During the expedition on HMS Beagle he collected over 5,436 skins, bones and carcasses of various creatures. His experiences and findings led him to question many of the accepted beliefs concerning life's origins.

In 1838 he pinned down his theory of natural selection proper – see 'The big idea' boxout for more details. Over the next 20 years, he continued to refine it until he received a letter from fellow British naturalist Alfred Russel Wallace proposing a collaboration. The fact that both men shared the same ideas led to the joint publication of their research. While Wallace's hypotheses on the subject were detailed, his hands-on research was lacking and Darwin's extensive fieldwork won out, with history since attributing the theory largely to the latter.

The publication of *On The Origin Of Species* the following year was therefore a landmark

A life's work

Famous for describing the evolution of humanity, we chart Darwin's own evolution through the 19th century

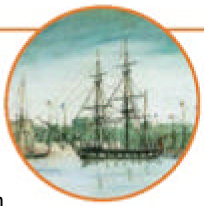


1809
Charles Darwin is born in Shrewsbury, England. His parents are Robert (above) and Susannah Darwin.

1818
In June, Darwin goes to Shrewsbury School as a boarder, where he studies for seven years.

1825
Darwin signs up for medical courses at the University of Edinburgh with elder brother Erasmus.

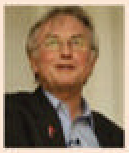
1827
He is admitted to Christ's College Cambridge to study not science but divinity.



1831
Accepts an offer to join a voyage on HMS Beagle which sets sail on 27 December.

IN THEIR FOOTSTEPS...

Joseph Hooker
Sir Joseph Dalton Hooker was one of Darwin's closest friends and classified the plants he collected in the Galápagos Islands. Hooker also played a key role in the formulation of Darwin's theory of natural selection, offering critical feedback during the drafting process, and was the first recognised man of science to support his radical ideas.



Richard Dawkins
British evolutionary biologist Richard Dawkins holds Charles Darwin as one of his major influences. Since reading Darwin's work at university, Dawkins has forged a career in biology that has seen him publish numerous acclaimed titles including The Greatest Show On Earth, which claims to lay down concrete evidence for evolution.

DID YOU KNOW? *From a young age Darwin collected and performed experiments on stones and beetles with his brother*

The HMS Beagle spent just five weeks in the Galápagos Islands, but that was long enough for Darwin's research purposes

moment for Darwin – and for science as a whole. To a degree it was a bringing together of various ideas that had already been mooted by other biologists but unproved. While Darwin did not supply concrete evidence for evolution, the work's lucidity and logic meant that, towards the end of the 1870s, the scientific community, and society as a whole, had accepted his views.

Darwin followed up this groundbreaking title in 1871 with *The Descent Of Man, And Selection In Relation To Sex*, where he applied his own evolutionary theory specifically to human's evolution from apes. This book was incredibly popular from the word go, with a reprint ordered within just three weeks of publication. Three months after its release, 4,500 copies had been sold – a testament to his rising fame.

Darwin died on 19 April 1882 from heart disease and, after a request by his colleagues, was granted a state funeral at Westminster Abbey, buried alongside other famous scientists John Herschel and Isaac Newton.

Top 5 facts: Charles Darwin

1 Family guy

Darwin had ten children, though two died while still young. Three of his sons went on to become members of the Royal Society themselves.

2 On the money

Darwin is commemorated in the UK with his portrait printed on £10 banknotes, alongside a hummingbird and the ship HMS Beagle.

3 School of thought

The school that Charles Darwin attended as a boy, Shrewsbury School, still exists, but it is no longer in the same building, which has since become a library.

4 Name gets around

Due to Darwin's great achievements in the field of natural history, more than 120 species and nine different genera have been named in his honour to date.

5 No sea-lover

HMS Beagle took five years to circumnavigate the globe, but Darwin only spent 18 months on board. From the day it set sail, he was afflicted with terrible seasickness.

Although some claim the significance of Galápagos finches to Darwin's theories has been overblown, more recent research indicates they are a good example of micro-evolution

Perhaps the most famous resident of the Galápagos, the giant tortoise

> "The publication of On The Origin Of Species was a landmark moment for Darwin – and for science"

1836
Lands back in England on 2 October and returns home to Shrewsbury.

1839
Marries Emma Wedgwood and has his first of ten children.

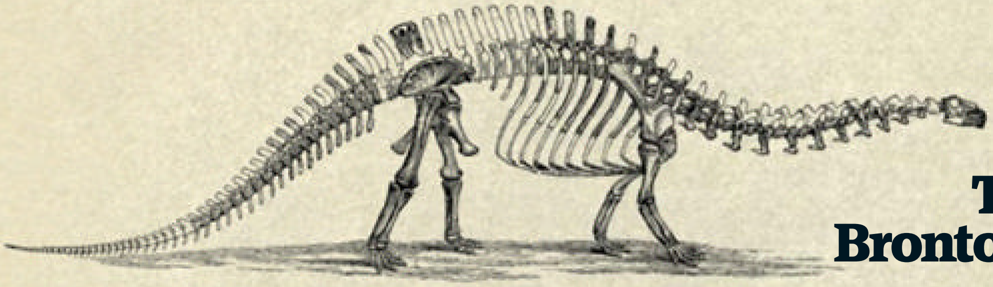
1858
Receives a letter from Alfred Russel Wallace who shares many of his ideas about the theory of natural selection.

1859
Publishes *On The Origin Of Species By Means Of Natural Selection, Or The Preservation Of Favoured Races In The Struggle For Life.*

1864
Receives the Copley Medal, the highest accolade from Britain's Royal Society.

1882
Darwin dies, aged 73, and is buried at Westminster.

© Mike Cornwell



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The real Brontosaurus

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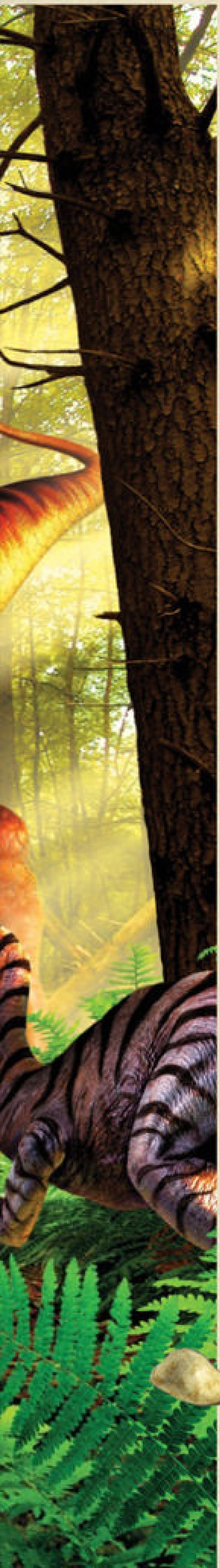
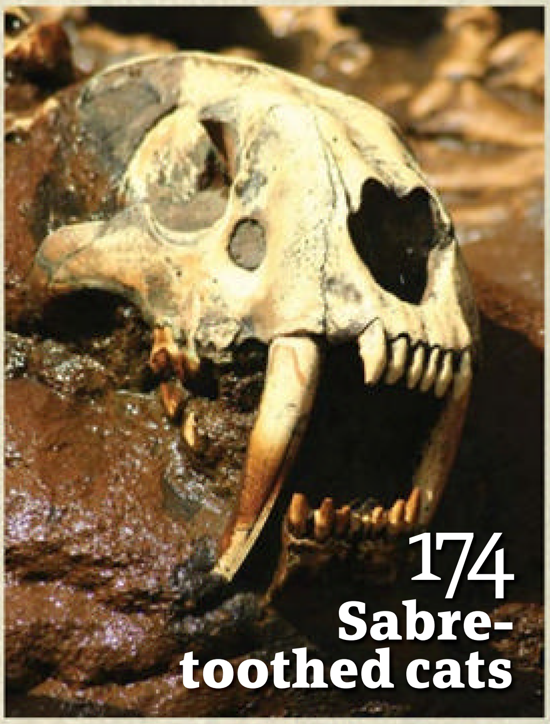


166
Biggest land mammal

© Alamy; SPL; Jerry LoFaro



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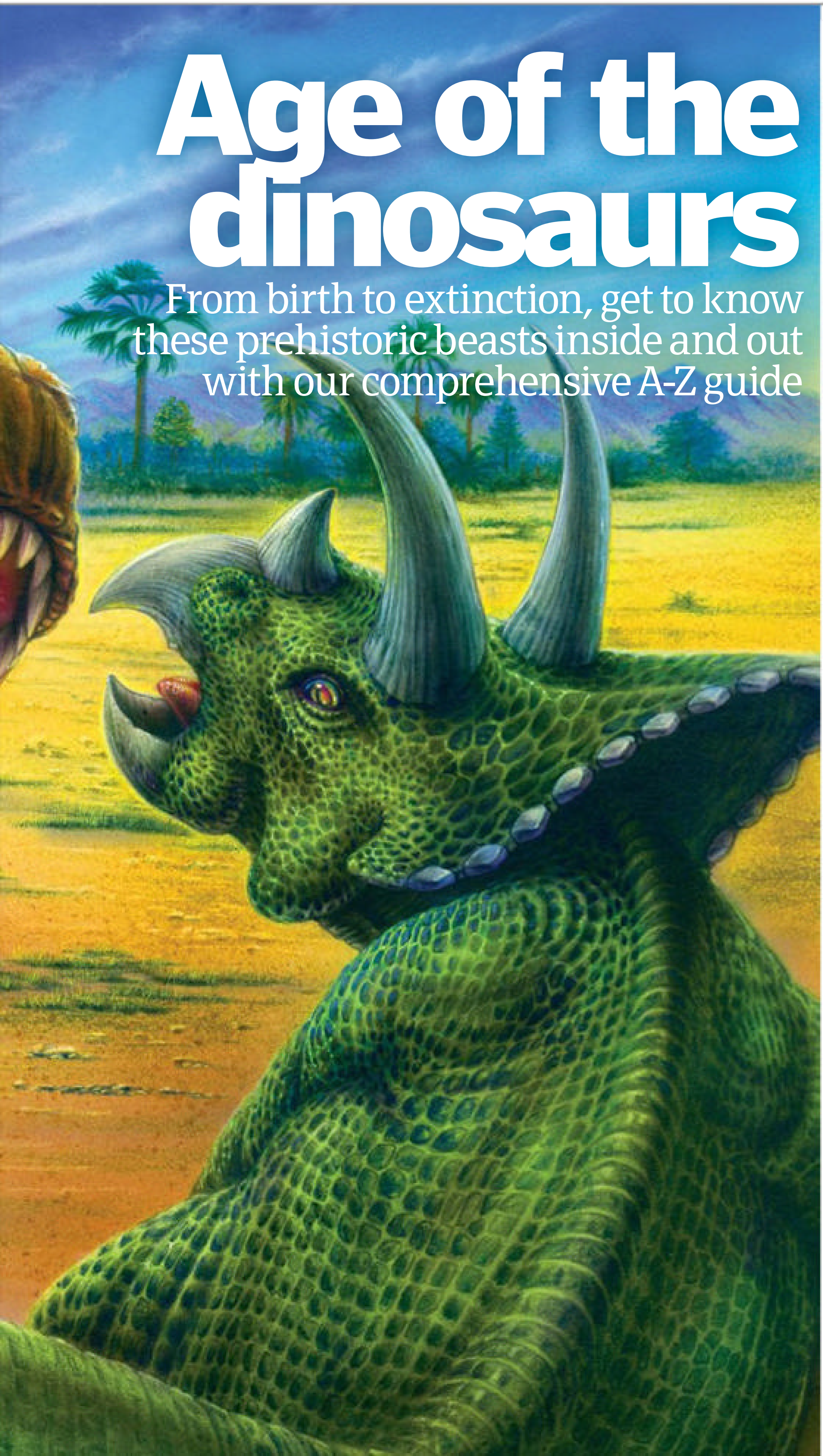
Prehistoric

Age of the dinosaurs

Age of the dinosaurs

From birth to extinction, get to know these prehistoric beasts inside and out with our comprehensive A-Z guide



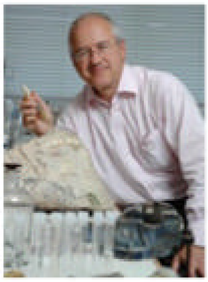
Dinosaurs have long sparked our imagination. From the Ancient Greeks' perception of their remains as evidence of a time when giants ruled Earth, right through to modern man's pursuit of their resurrection – be that in films like *Jurassic Park* or in laboratories via advanced DNA cloning techniques – dinosaurs remain a tantalisingly alien part of our world's history.

They may no longer roam the land like they did millions of years ago, but thanks to their genetic legacy and preserved remains they still remain a very real presence today.

From the fossils lying trapped in the ground through to the descendants flying above our heads, dinosaurs have unique tales to tell.

In this special History feature we take a closer look at this ancient world through an A-Z encyclopedia of all things dinosaur. You'll learn not just about the creatures themselves but the tools and techniques used to study them, and what Earth was like during their reign. This guide truly has it all, so strap yourself in and prepare for one wild, prehistoric ride...

Benton on a fossil dig near Albuquerque, New Mexico

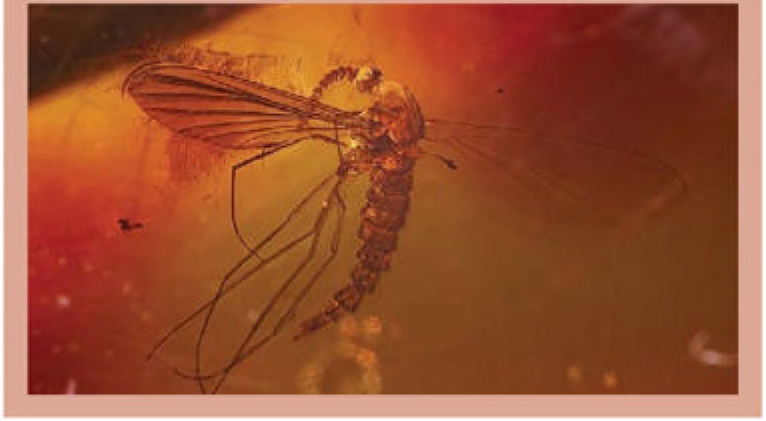


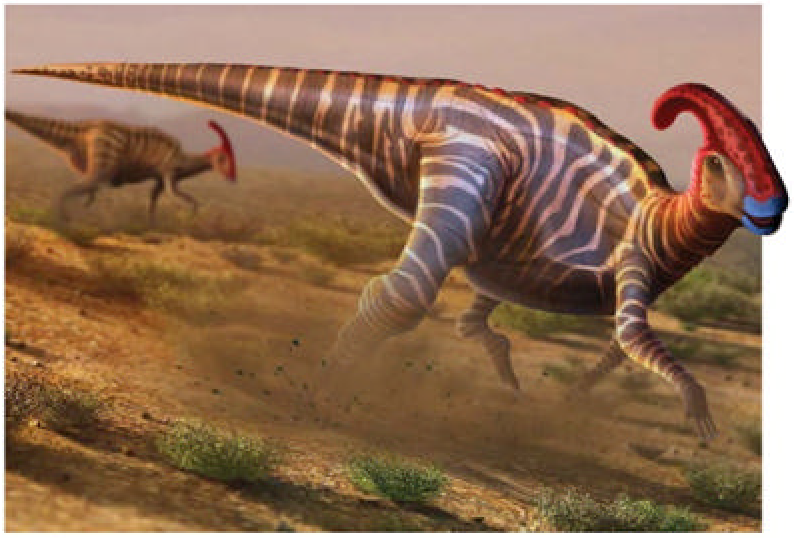
Professor Mike Benton, palaeontologist
Mike Benton is the Professor of Vertebrate Palaeontology at the University of Bristol, UK, and is a world-renowned dinosaur specialist. His areas of expertise include the diversification of life through time, the origin of dinosaurs and the end-Permian mass-extinction event. He can often be found working on digs in Russia and China. He offers some words of wisdom throughout our dino guide, but for a more in-depth interview, head to www.howitworksdaily.com.

A

Amber & dino DNA

Amber is fossilised tree resin that, due to a chemical change after burial in the ground, turns into a solid. Despite its stable state today, when the majority of the Earth's amber formed, it was far more fluid, which means many little organisms unwittingly became stuck within it – including plant matter and insects. Today these appear frozen within the amber and have been perfectly preserved. While one or two studies in the Nineties claimed to extract DNA from these organic inclusions (as portrayed in *Jurassic Park*), more recent research suggests this isn't possible. Scientists at the University of Manchester using advanced DNA sequencing in 2013 were not even able to find traces of DNA in copal (a precursor to amber) only 10,000 years old, so they're very doubtful that dino DNA could have survived from millions of years ago.





C

Communication in focus

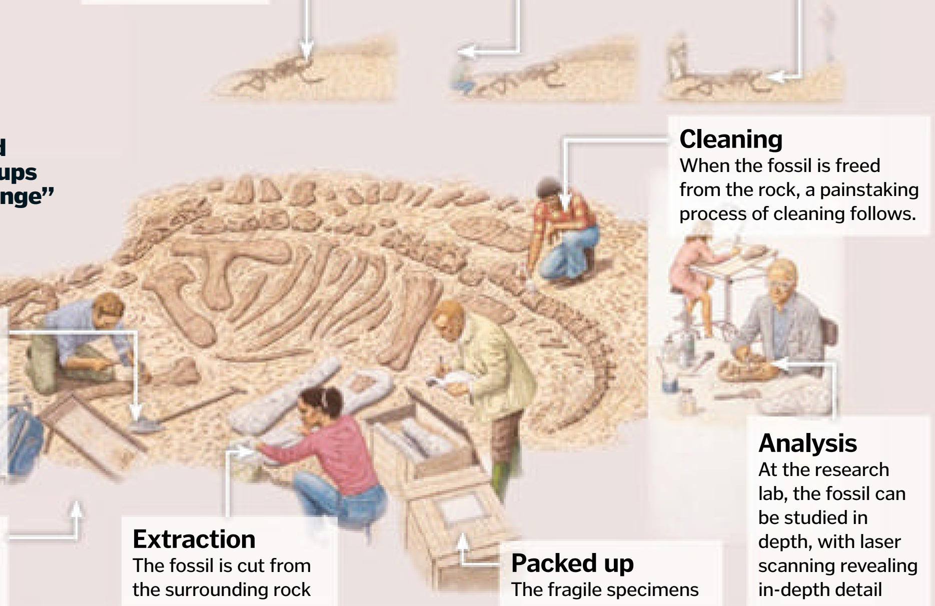
Dinosaurs, much like the many species of animal alive today, communicated in very different ways. From complex dance-like movements to more obvious calls and scent markings, each dino marked their territory, warned of potential predators and relayed information regarding food in its own unique way. One of the most interesting examples comes in the form of the hadrosaurid (above), a duck-billed dinosaur family sporting a distinctive bone crest on their heads. These crests were used as a resonating chamber for projecting their calls. Considering the hadrosaur's modest size and its wide range of predators, the ability to amplify its calls was no doubt a valuable defensive mechanism.

B

Bone secrets

Dinosaur bones are one of a palaeontologist's greatest sources of information, supplying data about their age, anatomy, distribution and much more. The bones of dinosaurs can only be found if they went through the process of fossilisation, where the tissue of the creature dissolves and gets replaced with minerals under pressure beneath the ground. Finding and extracting these fossilised bones is a major challenge for palaeontologists, with a carefully planned out dig site essential.

"Certain kinds of excavation and study out in the field can be for palaeoecology, trying to reconstruct food webs and modes of locomotion, or they can be about looking at patterns over time, going up metre by metre in rock formations and analysing fossil groups to see how they change"



Discovery
Most fossils are discovered at first only in part, with just a small fragment visible above the surface.

Shooting in situ
Photography plays a crucial part of any excavation. The specimen is continuously snapped from its discovery right through to removal.

Clearance
Once the fossilised bone has been photographed, the rock around it is carefully cleared to allow better access to the fossils.

Cleaning
When the fossil is freed from the rock, a painstaking process of cleaning follows.

Tools
Clearance is achieved with chisels, hammers and spades. The closer to the fossil the more delicate the tools.

Boundary
As soon as the fossil has been confirmed, a boundary is staked, protecting the area so palaeontologists can work unhindered.

Extraction
The fossil is cut from the surrounding rock and removed piece by piece, with each one meticulously labelled.

Packed up
The fragile specimens need to be transported with great care, with fossils placed in padded containers.

Analysis
At the research lab, the fossil can be studied in depth, with laser scanning revealing in-depth detail about the dinosaur.

KEY DATES
TRIASSIC
(*MA - MILLION YEARS AGO)

252.2 Ma The Triassic period begins, marking the beginning of the Mesozoic era. The first dinosaurs emerge.

252.2 Ma The Induan, the first stage of the Early Triassic, is characterised by a hot and largely deserted world.

250 Ma Archosauriformes, a clade of diapsid reptiles, evolve and take over all semi-aquatic environments.

225 Ma An early gliding reptile called Sharovipteryx mirabilis evolves, able to fly between tree habitats.

216 Ma The theropod Coelophysis flourishes on land. A slenderly built carnivore that walks on two legs.

201.3 Ma The Triassic-Jurassic extinction event wipes out nearly 30 per cent of marine life.

D

Diplodocus: a dino titan

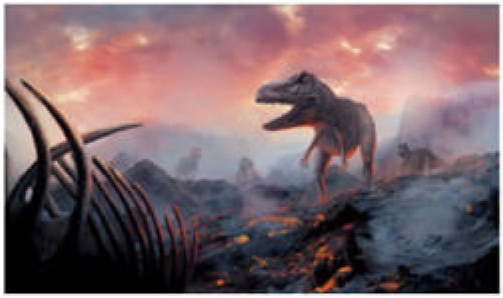
Of all the dinosaurs that lived on Earth few can truly lay claim to be a terrestrial giant – but the Diplodocus can. Built like a suspension bridge, the Diplodocus measured over 25 metres (82 feet) long – that's longer than five African elephants! It weighed over 12 tons, roughly 170 times more than the average human. It had an incredibly long neck and counterweight tail, the former used to elevate its head into the foliage of trees for food, while the latter was its primary form of defence. With a typical Diplodocus estimated to have lived between 50 and 80 years, it also had one of the longest life spans of any dinosaur from the Jurassic period.

F

Feathered fiends

Since palaeontologists began uncovering dinosaur remains in the 19th century, our depictions of them in the flesh have been largely coloured by a few initial artist impressions, with figures such as Charles Knight often drawing species in inaccurate postures and with factually incorrect sizes, colours and features. Based on current evidence, the lack of feathers on most species is one of the most obvious flaws in these early depictions, with half of all non-avian theropods now thought to have been partly feathered. The main cause for these misassumptions has been the lack of evidence, with feathers and soft tissues rarely preserved like fossilised bone.

> **"Colour in dinosaur feathers was a topic I think people thought that we would never know the answers to. But we were able to rely on a fair number of fossil feathers that were exceptionally well preserved and deep within their internal structure we could see colour-bearing organelles. So by using some smart observations and techniques we have proved it to be possible"**



E

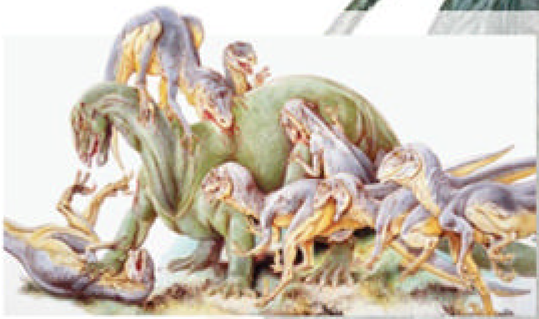
Extinction

Dinosaurs perished some 65 million years ago in what is known as the K-Pg (formerly K-T) extinction event. This cataclysmic event at the Cretaceous-Palaeogene boundary led to 75 per cent of all species on Earth dying off. From the smallest ocean plankton to the largest land beasts, the K-Pg extinction event resulted in devastation at every level of the world's ecosystems, with all non-avian dinosaurs eradicated. The current theory for the catalyst of this global wipeout is an asteroid impact in South America, but the real cause for such widespread carnage was not the impact itself but its knock-on effects. These include plants not being able to photosynthesise due to dust blocking out the Sun plus a series of epic tsunamis and fire storms.

G

Genetic legacy

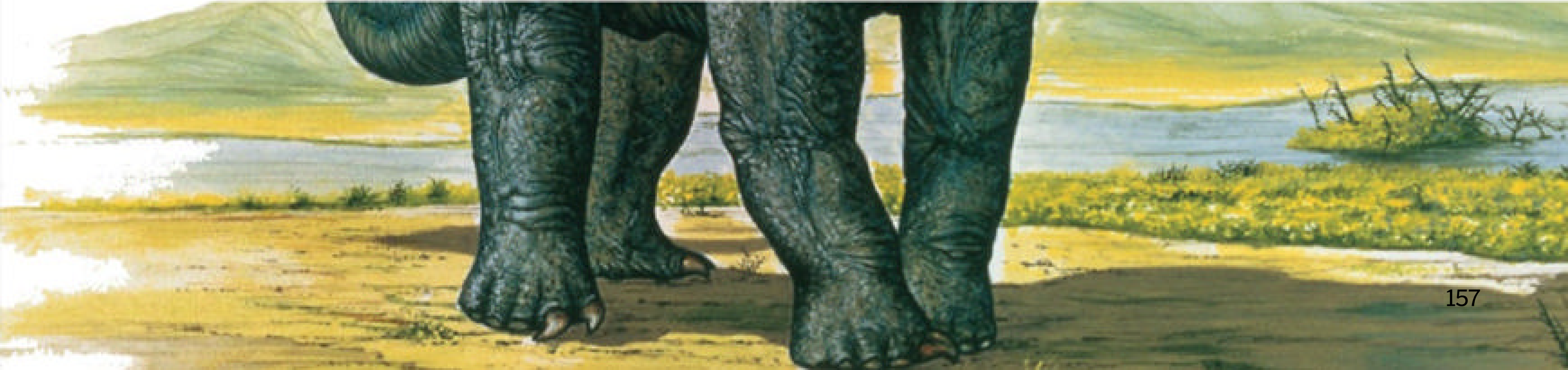
Today the study of dinosaurs is entering an exciting new age, where we can achieve an unprecedented level of accuracy through cutting-edge analysis. After a T-rex's soft tissue was discovered within a bone sample, we can now study things like proteins, blood vessels and other micro-anatomy to help us determine how individuals lived and died, as well as how dinos evolved.



H

Hunting strategies

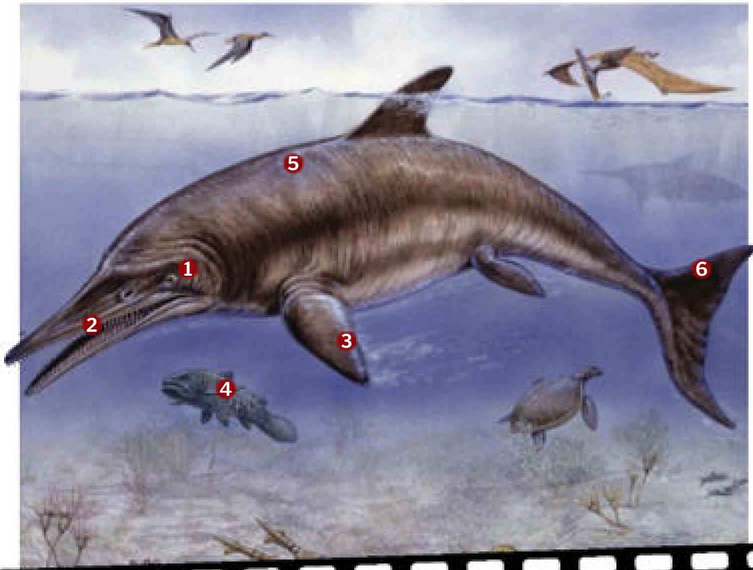
Whether dinos hunted and scavenged alone like the T-rex or in large packs like the Deinonychus – the model for the Velociraptor in *Jurassic Park* – carnivorous dinosaurs were no doubt the apex predators on Earth. However, debate rages as to how co-ordinated dinosaur pack hunters were. Since first described in 1969 by palaeontologist John Ostrom, the Deinonychus has been imprinted in the public consciousness as a highly intelligent, synchronised team hunter. However, many modern dino experts disagree with this assumption, believing that while Deinonychus did move and chase prey in groups, they did so with little co-ordination, with each individual simply acting out of self-interest rather than working together like, say, lions.



I

Ichthyosaurus

Although technically not a true 'dinosaur', Ichthyosaurus, or 'fish lizard', filled the same niche in Earth's oceans and was one of the most dominant marine species of the Mesozoic era (252-65.5 Ma) Resembling today's dolphins, Ichthyosaurus measured in at roughly two metres (6.6 feet) in length and was capable of cruising through the water at around 40 kilometres (25 miles) per hour, enabling it to catch fish and squid with ease. The fact that Ichthyosaurus had a very large pair of eyes protected by a pair of bony, structural-supporting rings has led some palaeontologists to believe the species frequently hunted at great depths where pressure was very high.



① **Eyes** Large eyes were protected by rings of bone to keep them intact at depths.

② **Teeth** The jaws were lined with rows of sharp, conical teeth, primed for shredding soft prey such as squid.

③ **Fins** Stunted limb-like fins were used for stability and manoeuvring rather than propulsion.

④ **Prey** Fish, squid and marine reptiles were the main food of choice, but the sharp teeth could crush shellfish as well.

⑤ **Body** A streamlined body, with a curved spine and no neck. By undulating it could alter its speed and direction.

⑥ **Tail** It had a top speed of 40km/h (25mph) came courtesy of the bilobed, shark-like tail.

J

Jurassic lark

Five factual bloopers from the famous Hollywood films

Timing problems
Jurassic Park portrayed many famous dinosaur species, including T-rex and Triceratops, but most of the animals shown actually lived in the Cretaceous period, not the Jurassic.

Out of proportion
One thing the film's producers definitely need punishing for is the depiction of the park's Velociraptors. Portrayed as being as tall as a man, in reality they barely stood 0.5m (1.6ft) off the ground.

Feather-brained
Another massive omission in *Jurassic Park* was the lack of any feathers. Most dinosaur species, especially sauropods, had some plumage on their bodies.

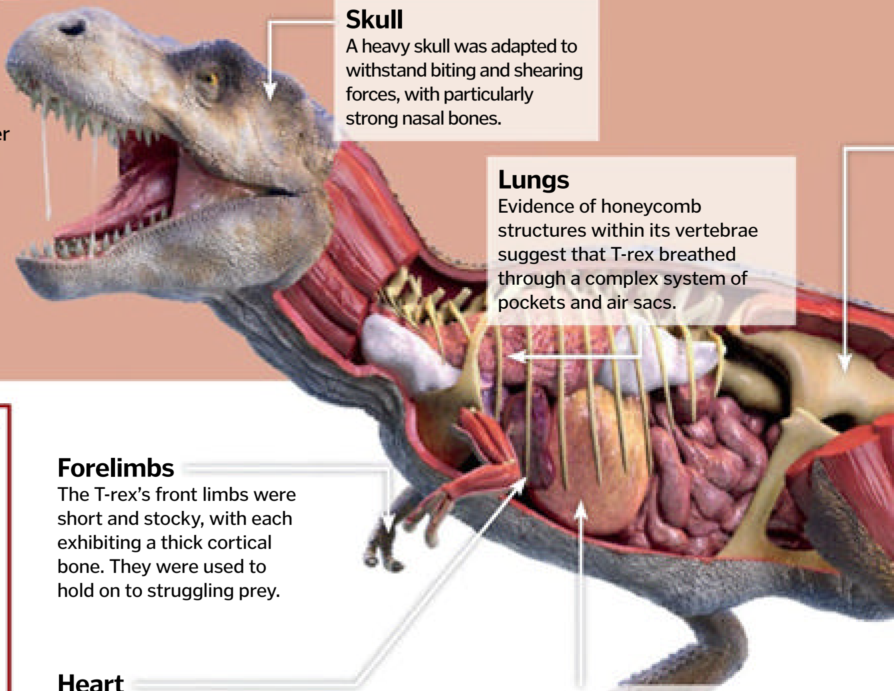
No grudge match
In the third film, the Spinosaurus is shown going toe-to-toe with its supposed arch-nemesis, the T-rex. In reality they never met as they lived on different continents of prehistoric Earth.

Spit on a grave
Another creative addition was Dilophosaurus's ability to spit out poison. However there is no evidence to suggest it could do this; neither did it have a frilled neck.

K

King of the dinosaurs

While not the biggest or smartest, the Tyrannosaurus rex was no doubt the closest to a king the dinosaurs ever had. A colossal bipedal carnivore, the T-rex measured in at over four metres (13 feet) tall and over 12 metres (39 feet) long, weighing over seven tons. It was no slow-poke either, with computer models estimating that the dino was capable of hitting a top speed of around 29 kilometres (18 miles) per hour chasing prey. When it caught up it could quickly dispatch them with a single bite that had a force of three tons – the equivalent weight of a fully grown African elephant. Yikes!



Skull
A heavy skull was adapted to withstand biting and shearing forces, with particularly strong nasal bones.

Lungs
Evidence of honeycomb structures within its vertebrae suggest that T-rex breathed through a complex system of pockets and air sacs.

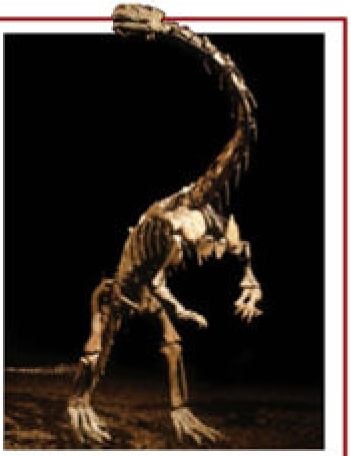
Forelimbs
The T-rex's front limbs were short and stocky, with each exhibiting a thick cortical bone. They were used to hold on to struggling prey.

Heart
With a body bigger than a bus, the T-rex needed a huge pump to transport blood at adequate pressure. Current estimates suggest its heart was over 100 times bigger than a human's.

Stomach
The T-rex had a hardy stomach due to its high-meat diet and the fact that it scavenged frequently from long-dead carcasses. Analysed T-rex dung has revealed many fragments of bone.

L Lufeng: a fossil treasure trove

One of the most prolific dinosaur hotspots in the world is Lufeng in Yunnan Province, China. Since 1938, 33 species, each with its own complete fossil, have been found there. Some of the finds have been record-breaking, with many of the vertebrate fossils uncovered the oldest on record – eg, the Lufengosaurus fossil (pictured right) dates from 190 million years ago. Lufengosaurus was a genus of prosauropod that lived during the Early Jurassic period. Tourists can see many excavated dinosaur finds at the nearby Lufeng Dinosaur Museum.



KEY DATES

JURASSIC

(*MA - MILLION YEARS AGO)

201.3 Ma The middle period of the Mesozoic era, with the Jurassic following the Triassic mass-extinction.

199.6 Ma The large marine sauropterygian reptile Plesiosaurus evolves; an apex predator of oceans.

183 Ma The Pliensbachian stage ends with anoxic ocean waters and wide-scale marine extinctions.

175 Ma The first phase of the supercontinent Pangaea's breakup into several continents begins.

154 Ma The famous Diplodocus evolves due to the dominance of sauropods in the dino kingdom.

145 Ma The Tithonian epoch of the Late Jurassic ends, with the Cretaceous period following.

M

Mesozoic world

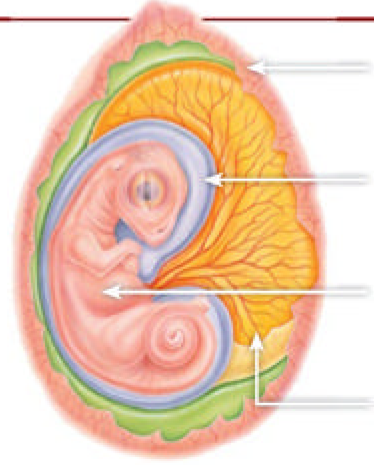
Beginning 252.2 million years ago and coming to a close about 65 million years ago, encompassing the Triassic, Jurassic and Cretaceous periods, the Mesozoic era truly defined the age of dinosaurs. All the famous species you can think of lived within it.

The Mesozoic was generally warm with a significantly smaller temperature differential between the equatorial and polar regions – ideal conditions for the emergence and proliferation of flora and fauna. The Mesozoic was also famous for being the time period where the ancestors of today's major plant and animal groups emerged.

N

Nesting & dinosaur eggs

Dinos organised their nests, laying their eggs in patterns suggesting complex social behaviours. Palaeontologists have identified two main types of egg-laying strategies – clutches and linear patterns – further divided by the shape of the nest and distribution of eggs. For example, the ornithopod Maiasaura nests generally consisted of bowl-shaped excavations roughly two metres (6.6 feet) wide and 0.8 metres (2.6 feet) deep, the opening covered by loose vegetation. Each nest was spaced roughly seven metres (22 feet) apart and was used by their offspring until they were over a metre (3.3 feet) long.

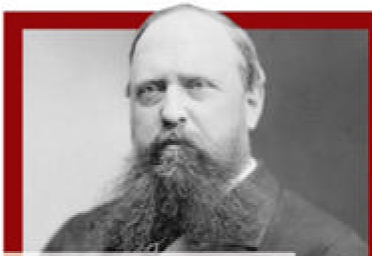


Outer shell
Dinosaur eggs were elongated and had hard, brittle shells. Some of the largest found to date were 0.6m (2ft) long.

Amniotic membrane
Encompassing the dinosaur was a thin membrane, helping keep the embryo hydrated during development.

Embryo
At the centre lay the dinosaur embryo that, depending on the species, could take weeks or months to hatch.

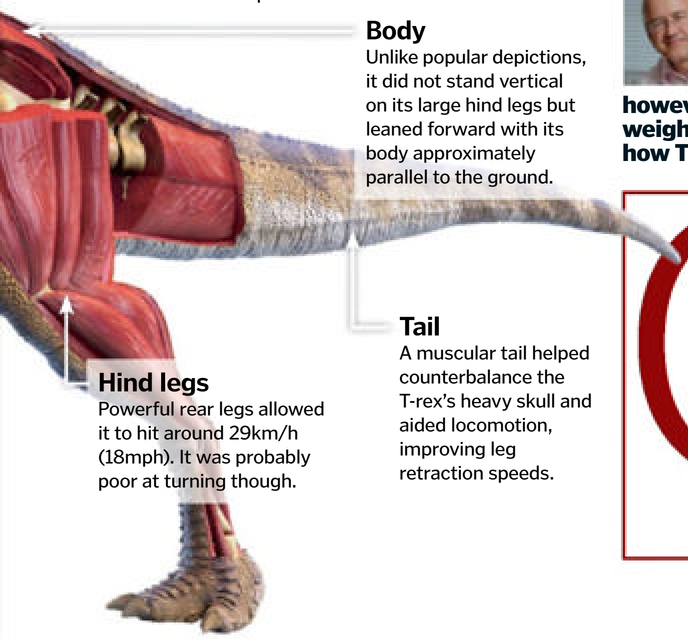
Yolk sac
This contained proteins and fat which served as food for the baby dino.



P

Palaeontology: key players

Most of our current knowledge of the dinosaur kingdom comes courtesy of palaeontologists, who dedicate their lives to uncovering the secrets of their prehistoric kingdom. From the earliest dinosaur hunters such as Othniel Marsh (left), who discovered and named the Allosaurus, Stegosaurus and Triceratops, to 20th-century scientists who revolutionised our understanding of the dinosaurs' legacy, such as John Ostrom who gained fame for his suggestion that birds were modern-day descendants, palaeontologists have helped provide tantalising glimpses of the prehistoric world. One of the more recent palaeontologists who has helped introduce dinosaurs to the general public is Dr Philip J Currie. He helped found the prestigious Royal Tyrrell Museum of Palaeontology.



Pelvis
The T-rex was a saurischian dinosaur, meaning it had a lizard hip arrangement. Its pubis bone pointed forward and down rather than backward and down like ornithischian species.

Body
Unlike popular depictions, it did not stand vertical on its large hind legs but leaned forward with its body approximately parallel to the ground.

Tail
A muscular tail helped counterbalance the T-rex's heavy skull and aided locomotion, improving leg retraction speeds.

Hind legs
Powerful rear legs allowed it to hit around 29km/h (18mph). It was probably poor at turning though.

"Weighing something like five tons yet walking bipedally makes the T-rex incredibly interesting, as it pushes the absolute limits of what is possible. I mean, you look at an elephant and think, 'Wow, that's amazing', however, an elephant has to walk on four legs and weighs roughly the same amount, so understanding how T-rex functioned is a fascinating area of research"

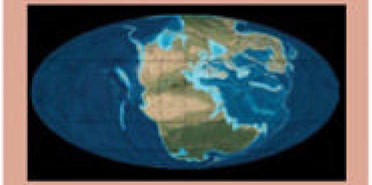
Q

Queensland

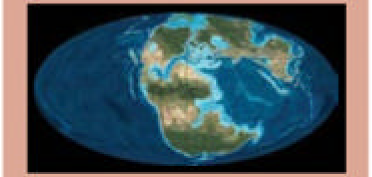
If you were to visit Queensland's more remote regions, you may very well find yourself standing face to face with one of many 100-million-year-old beasts. That's because Queensland's outback was once part of the Great Inland Sea, a huge swampy inland ocean that existed in the age of the dinosaurs. As such, hundreds of fossils have been excavated from this region and there is even an established 'Australian Dinosaur Trail' that tourists can follow.

O

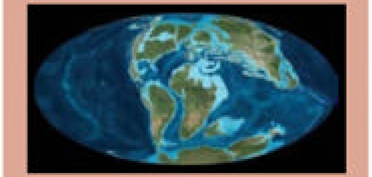
Oceans & continents



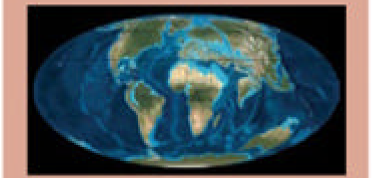
1 Triassic
At the beginning of the Mesozoic era in the Early Triassic period, all the land on Earth was joined together into the supercontinent of Pangaea, itself surrounded by the superocean Panthalassa.



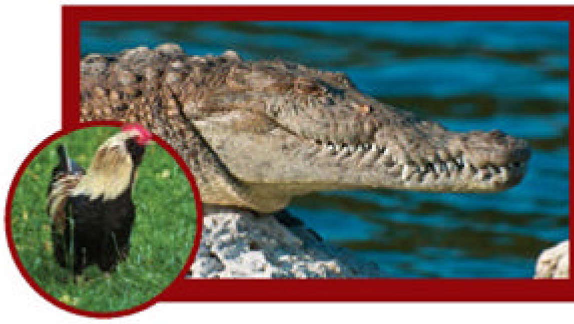
2 Jurassic
As the Mesozoic progressed and the Triassic made way for the Jurassic period, plate tectonics split Pangaea into two mega-continents: Gondwana and Laurasia, separated by the Tethys Sea.



3 Cretaceous
As the Mesozoic came to a close, Gondwana and Laurasia had split into many of the continents we know today, including North and South America and Antarctica.

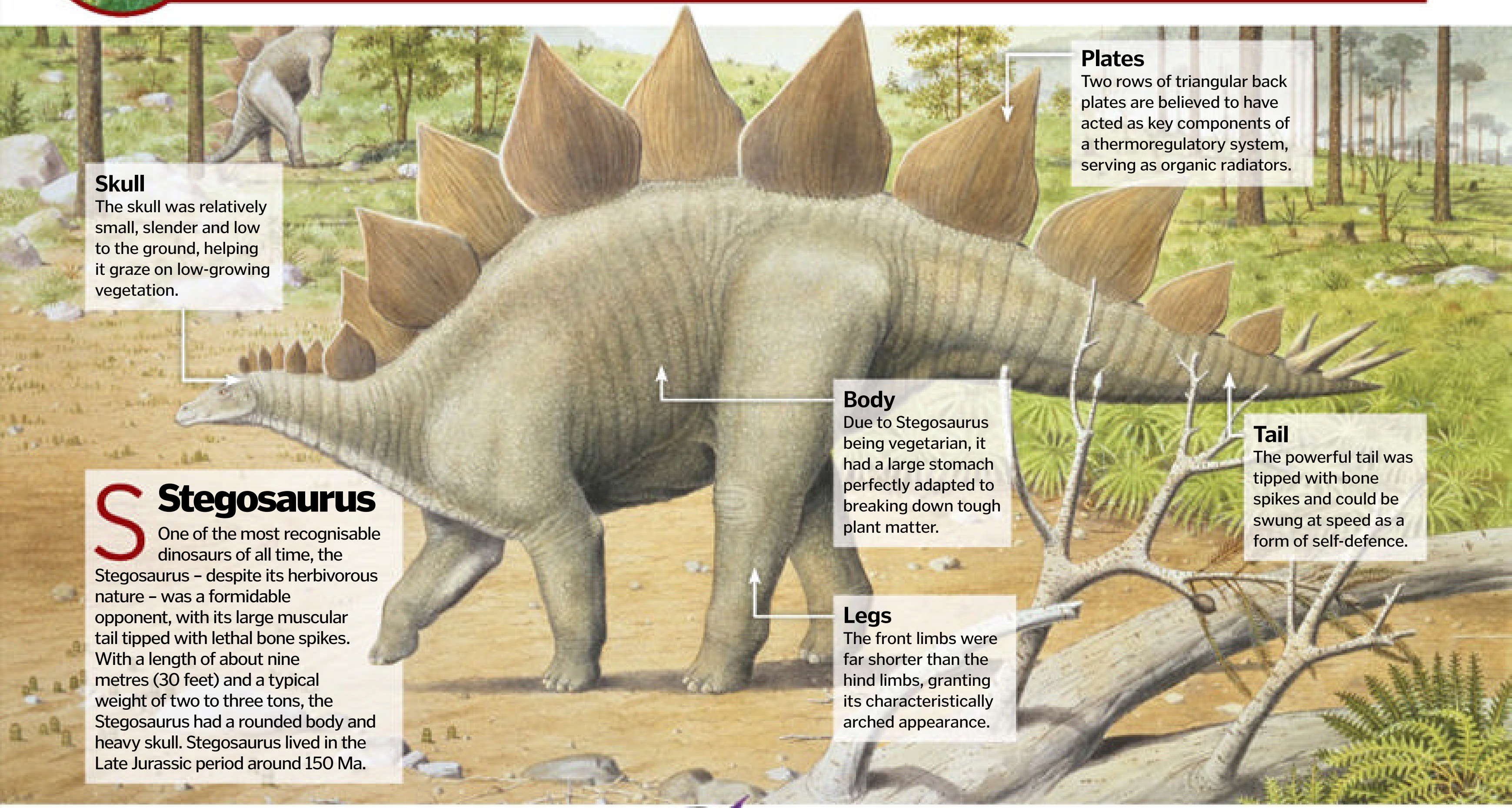


4 Palaeogene
In the Palaeogene period – the era immediately following the K-Pg extinction event – those continents continued to move to their current positions.



Relatives in the modern world

Massive scientific effort has been put into identifying which creatures today can trace their roots back to these prehistoric beasts. One of the best examples of this was the hunt for the nearest living relative of the once-mighty T-rex, undertaken by a research team at the North Carolina State University in 2007. To go about this the researchers sequenced proteins from a 68-million-year-old T-rex tissue sample and, much to their surprise, discovered that the king of the dinosaurs' molecules showed remarkable similarity to the common chicken and that its collagen makeup was almost identical. So, at least for the time being, the humble chicken is the rightful ruler of the Earth…



Plates
Two rows of triangular back plates are believed to have acted as key components of a thermoregulatory system, serving as organic radiators.

Skull
The skull was relatively small, slender and low to the ground, helping it graze on low-growing vegetation.

Body
Due to Stegosaurus being vegetarian, it had a large stomach perfectly adapted to breaking down tough plant matter.

Tail
The powerful tail was tipped with bone spikes and could be swung at speed as a form of self-defence.

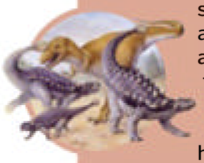
Legs
The front limbs were far shorter than the hind limbs, granting its characteristically arched appearance.

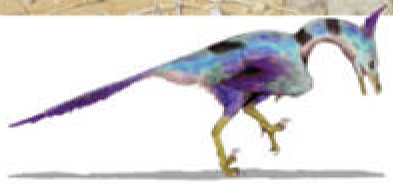
Stegosaurus

One of the most recognisable dinosaurs of all time, the Stegosaurus – despite its herbivorous nature – was a formidable opponent, with its large muscular tail tipped with lethal bone spikes. With a length of about nine metres (30 feet) and a typical weight of two to three tons, the Stegosaurus had a rounded body and heavy skull. Stegosaurus lived in the Late Jurassic period around 150 Ma.

Tall tails

You'll struggle to find a dinosaur without a tail. This is because the majority of dinosaurs used their tails for two important roles: the first being balance and the second being self-defence. Large animals like the T-rex and Diplodocus, thanks to their skulls or necks, were very top-heavy. They needed long and heavy tails to counterbalance this, especially when running. Other smaller creatures such as Ankylosaurus (left) used its tail when under attack, evolving a large bony club at the end which could painfully bludgeon assailants.





Unenlagia: half bird, half dinosaur

One of the most telling links between dinosaurs and birds is the Unenlagia, a genus of theropod dinosaur from the Late Cretaceous that in almost all aspects, aside from flight, resembles a modern bird. It was discovered in 1997 and to date two species have been confirmed – U comahuensis and U paynemili – both of which share an almost identical pelvic structure to the early bird species Archaeopteryx.

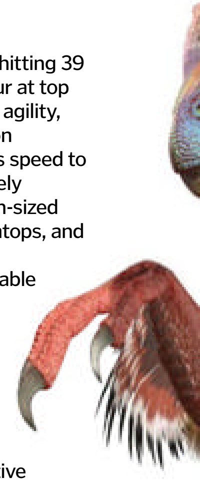
Velociraptors debunked

Due to their appearance in the *Jurassic Park* films, the Velociraptor is easily one of the most recognisable of all species. Importantly though, this image of the Velociraptor is way off the mark in terms of reality.

In contrast to the movie monster, research evidence suggests that the Velociraptor was actually a feathered dinosaur under 0.6 metres (two feet) in length, with colourful plumage used in mating rituals and visual displays. The species also had hollow bones, much like birds, and built large nests to protect their offspring.

The Velociraptor did impress in ground speed – one thing *Jurassic Park* got right – with it capable of hitting 39 kilometres (24 miles) per hour at top speed and boasting amazing agility, being able to change direction incredibly quickly. It used this speed to chase down prey, which largely consisted of small to medium-sized herbivores such as Protoceratops, and then kill them with its nine-centimetre (3.5-inch) retractable claws and sharp teeth.

As mentioned in 'Hunting strategies' new research suggests that, while sociable compared with other carnivorous species, Velociraptors were not apex pack hunters, with co-operative kills possible but infrequent.



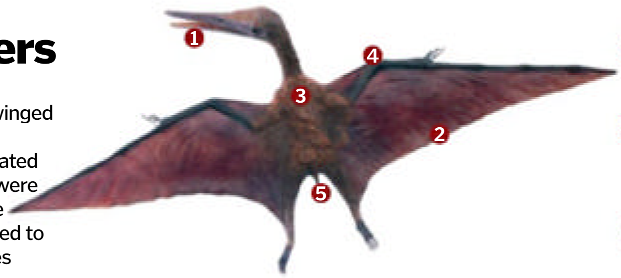
KEY DATES
CRETACEOUS
(*MA - MILLION YEARS AGO)

145 Ma	125 Ma	99.6 Ma	68 Ma	67 Ma	65.5 Ma
The Cretaceous period begins with all types of dinosaurs dominating on land, sea and air.	After 15 million years of marine dominance, the plesiosaur Leptocleidus dies out once and for all.	The Albian age gives way to the Cenomanian, made famous for its dramatic, anoxic end event.	The giant herbivorous Triceratops becomes one of the last non-avian dinosaur genera to appear.	Tyrannosaurus rex takes over as the apex terrestrial predator on Earth until all dinosaurs are wiped out.	A massive space rock smashes into Earth, resulting in the K-Pg extinction event.

Winged wonders

While not technically dinosaurs, pterosaurs were very much the winged wonders of the dinosaur era. Flying reptiles that evolved throughout the Late Triassic and dominated the skies until the Late Cretaceous, pterosaurs were the earliest vertebrates currently known to have evolved powered flight. Pterosaurs are not related to modern-day birds or bats, with the many species evolving earlier and separately.

The genus Pterodactylus was one of the most notable, with the species Pterodactylus antiquus one of the most impressive, with a toothed beak, large eyes and clawed wings. In terms of wingspan P antiquus could extend its wings up to a metre (3.3 feet) and had a long, narrow skull packed with dozens of sharp, pointed teeth. It used these to snap up fish and smaller reptiles.



"Microraptor was a small, four-winged dinosaur… very close to the origin of birds. Its remains show it had wings on its arms and legs. It couldn't fly properly, but used its wings to glide. This shows the origin of flight in birds and their ancestors was much more complex than expected"

❶ Beak
Up to 90 teeth in the long beak intermeshed when the jaw was closed, and were perfect for grabbing fast prey.

❷ Wings
A wingspan of around 1m (3.3ft) was typical for Pterodactylus, with the wings structured in a way that indicates it would have flown like an albatross.

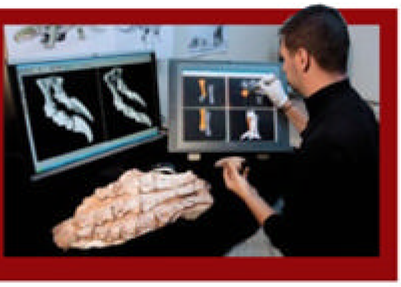
❸ Body
Not as large as depicted in fiction, Pterodactylus was very lightly built with hollow bones and a long neck.

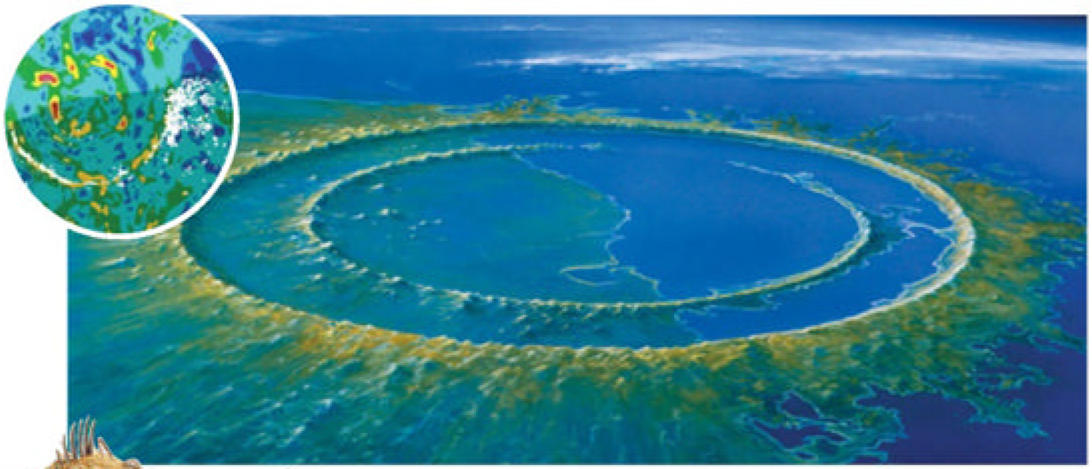
❹ Limbs
Pterosaurs evolved a unique pteroid bone on the wrists of their forearms, used to support the forward wing membrane located between the wrist and shoulder.

❺ Tail
Unlike some other pterosaurs, Pterodactylus had a relatively short, stubby tail.

X-raying prehistoric remains

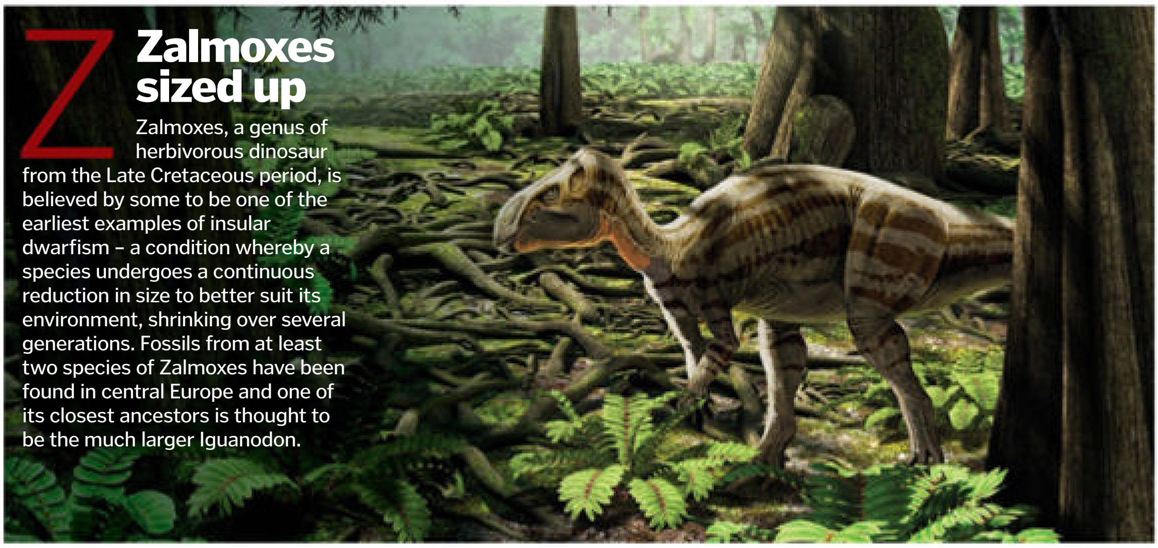
X-ray scanners have become incredibly useful and important tools in the world of palaeontology as they can reveal many fossils and features that otherwise would remain hidden. For example, in November 2013, researchers in Germany used an X-ray machine to unveil the detailed structure of a fossil trapped within a plaster cast, all without ever having to break it open and risking damage to the specimen. What's more, the researchers then made use of a 3D printer to re-create the X-ray scans in solid form, allowing palaeontologists to pick up and handle a cast of the fossil as fine and detailed as the real thing. Modern technology is set to further our understanding of dinosaurs by no bounds.





Yucatán impact

The colossal Chicxulub crater in the Yucatán Peninsula, Mexico, since its discovery in the Seventies, has hinted as to how 75 per cent of all life on Earth was eradicated around 65.5 million years ago. The crater indicates that a space rock – probably an asteroid – at least ten kilometres (six miles) across impacted Earth. As a result of the extensive damage caused by the collision and consequently by tsunamis, dust storms and volcanism, it caused a collapse in the world's ecosystems, with all non-avian dinosaurs at the top of the death list. The impact's link to the K-Pg mass extinction has recently been reaffirmed with even more detail, with researchers linking the two events in time to within 11,000 years. That said, various phenomena, such as dramatic climate swings, also contributed to the end of the dinosaurs post-impact.



Zalmoxes sized up

Zalmoxes, a genus of herbivorous dinosaur from the Late Cretaceous period, is believed by some to be one of the earliest examples of insular dwarfism – a condition whereby a species undergoes a continuous reduction in size to better suit its environment, shrinking over several generations. Fossils from at least two species of Zalmoxes have been found in central Europe and one of its closest ancestors is thought to be the much larger Iguanodon.

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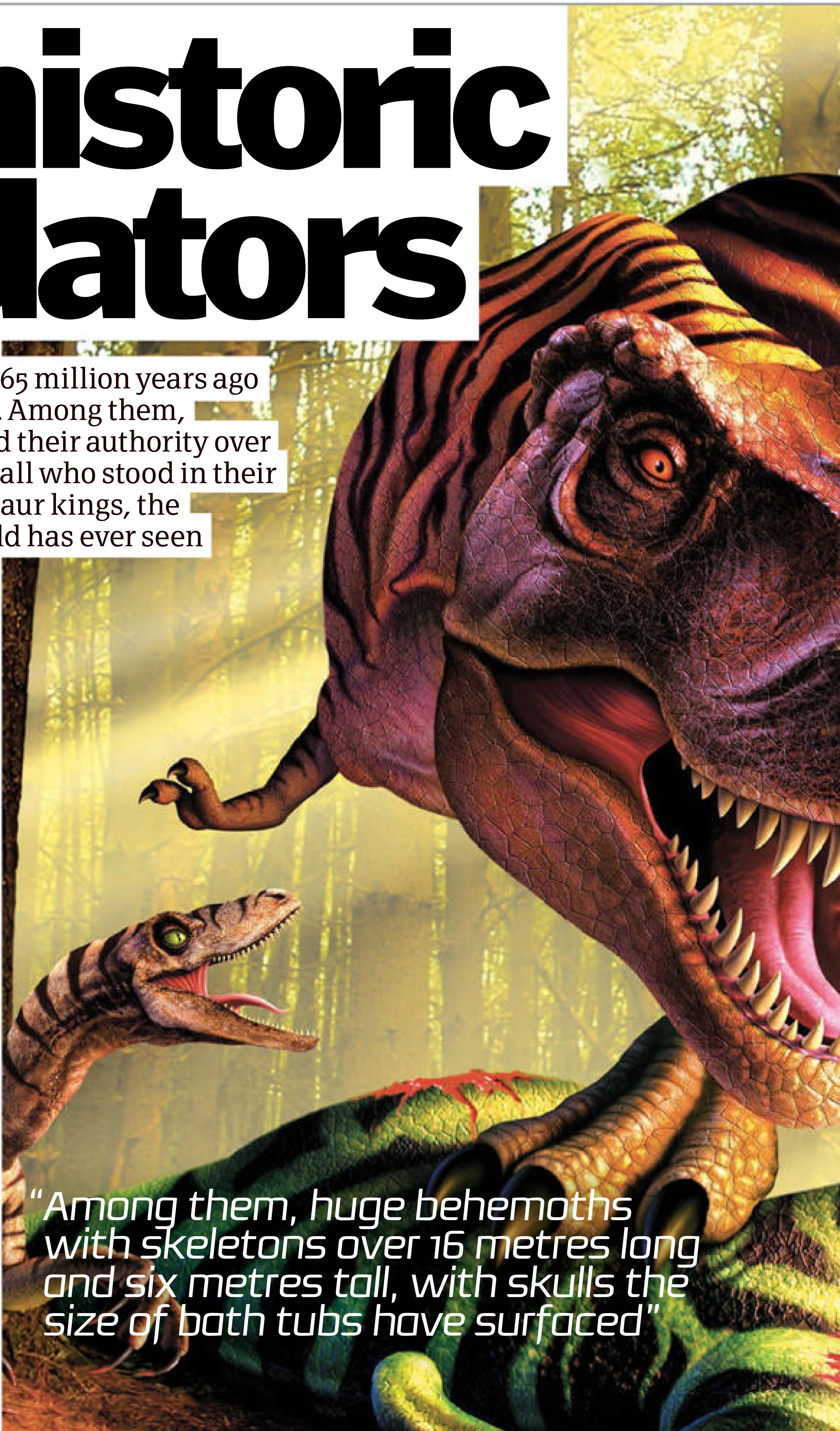
Prehistoric predators

Until they were wiped out 65 million years ago dinosaurs ruled the Earth. Among them, monstrous beasts stamped their authority over the menagerie, devouring all who stood in their way. These were the dinosaur kings, the largest carnivores the world has ever seen



Evolving from archosaurs (large lizards) in the latter part of the middle Triassic period, dinosaurs quickly gained a strong and prolific foothold all over Pangaea, the super continent which all our continents were once part of. Indeed, as the dominant terrestrial vertebrates through the Jurassic and Cretaceous periods, thousands of species of dinosaur have been unearthed as fossils by palaeontologists all over the world, with new discoveries being presented every year. Among them, huge behemoths with skeletons over 16 metres long and six metres tall, with skulls the size of bath tubs have surfaced and delivered a scary and disturbing glimpse into the creatures that once prowled the countries we still live in today.

Among the largest of these giants, a group of massive carnivorous theropods (bipedal dinosaurs) emerged throughout the Jurassic and Cretaceous periods, casting a shadow over the rest of the dinosaur population. The most famous of these is the Tyrannosaurus Rex, as made popular by the *Jurassic Park* films, however this type of theropod was but one of a host of killers and, amazingly, not the largest! Historically, of course, the reign of these carnivorous kings was cut short in the mass-extinction of the dinosaur population at the close of the Cretaceous period, when a 110-mile radius asteroid crashed into the Yucatán Peninsula, setting off a chain-reaction (tsunamis, dust clouds, temperature variation, food-chain collapse) of events that eventually led to their extermination.

Here, though, we explore the giddy heights of the pinnacle of dinosaur evolution, the time when nothing living on Earth could match these beasts for size and strength. Better run for cover then, as things are about to get prehistoric…

> "Among them, huge behemoths with skeletons over 16 metres long and six metres tall, with skulls the size of bath tubs have surfaced"

TOP ACTS OSAURS

Long neck
1 The tallest of all the dinosaurs was the giant Brachiosaurus, mainly thanks to its giraffe-like neck, which stood at a rather impressive height of 50 feet.

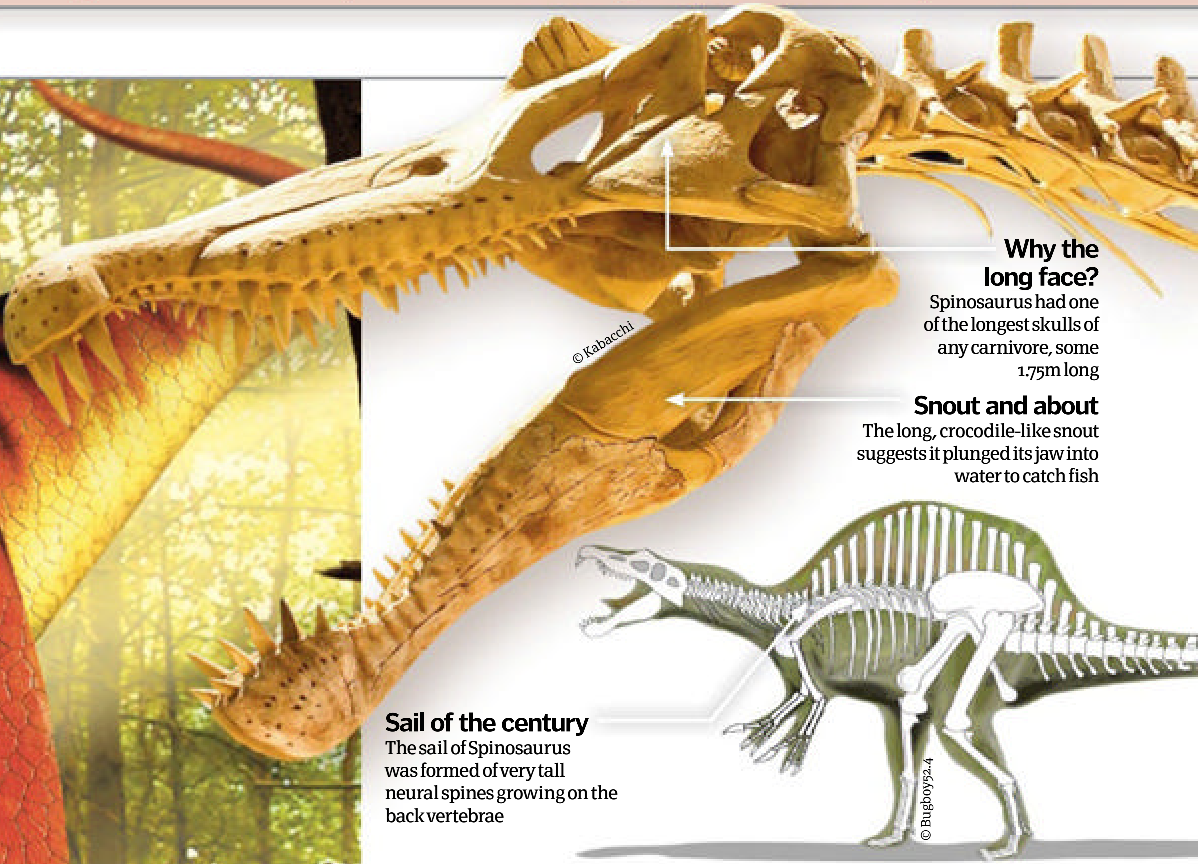
The shortest
2 In contrast, one of the smallest dinosaurs to roam the Earth was the Compsognathus, standing at a measly 1.5 feet tall and four feet long.

The fastest
3 Two of the quickest of all dinosaurs were the Ornithomimus and Gallimimus, which are estimated to have been able to reach speeds of 70mph.

Feathered
4 Contrary to their portrayal in films, many dinosaurs were actually feathered like birds, with the Sinosauropteryx being the first to be un-earthed by palaeontologists.

Velociraptor
5 The Velociraptor, made famous by the Jurassic Park films, was not actually as big as it was portrayed, standing at six feet long and only 1.9 feet high.

Image used with kind permission of Jerry Lofaro



© Kabacchi

Why the long face?
Spinosaurus had one of the longest skulls of any carnivore, some 1.75m long

Snout and about
The long, crocodile-like snout suggests it plunged its jaw into water to catch fish

Sail of the century
The sail of Spinosaurus was formed of very tall neural spines growing on the back vertebrae

© Bugboy52.4

CARNIVORE 1

Spinosaurus

Step aside T-Rex, this was the ultimate theropod…

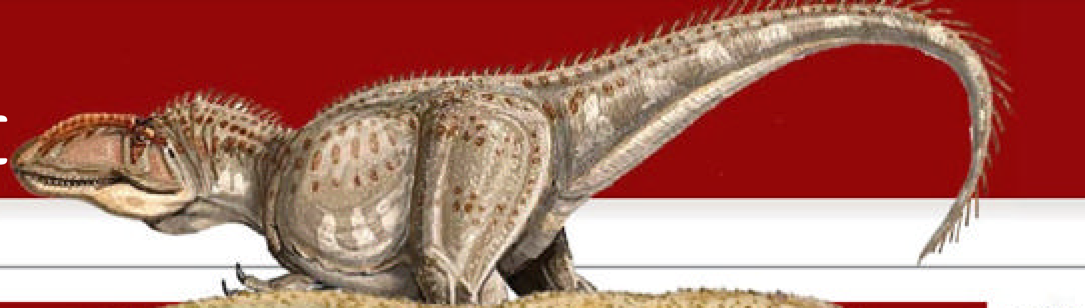
Bigger and arguably meaner than the Tyrannosaurus Rex, the Spinosaurus is thought to be the largest theropod dinosaur to ever roam the planet. Over 16 metres long, six metres high and weighing a monumental 12 tons, the Spinosaurus was a relatively common animal in the late Cretaceous period. Palaeontologists have found fossilised remains of the Spinosaurus in Morocco, Libya and Egypt, including a well preserved but now destroyed (blown-up in a World War II bombing run) specimen that included the lower jaw and vertebrae with complete spines. Spinosaurus was typical for a large theropod but differed in its skull and vertebrae construction. The snout of the 1.75-metre skull was long like a crocodile, with the nostril openings placed well back from the tip. Its teeth were also conical, rounded in a cross section and did not contain any serrations – these features suggest that the Spinosaurus plunged its jaw into water in order to catch fish. However, considering its size, jaw strength and number of teeth, it equally had no trouble in hunting small, medium and other large dinosaurs on land.

Not a dinosaur you'd want to meet down a dark alley…

The Statistics

Spinosaurus

Height: 6 metres
Length: 16 metres
Weight: 12 tons
Head size: 1.75 metres
Interesting fact: The spines on the Spinosaurus grew up to two metres tall
Fear factor: 9/10



CARNIVORE 2

Giganotosaurus

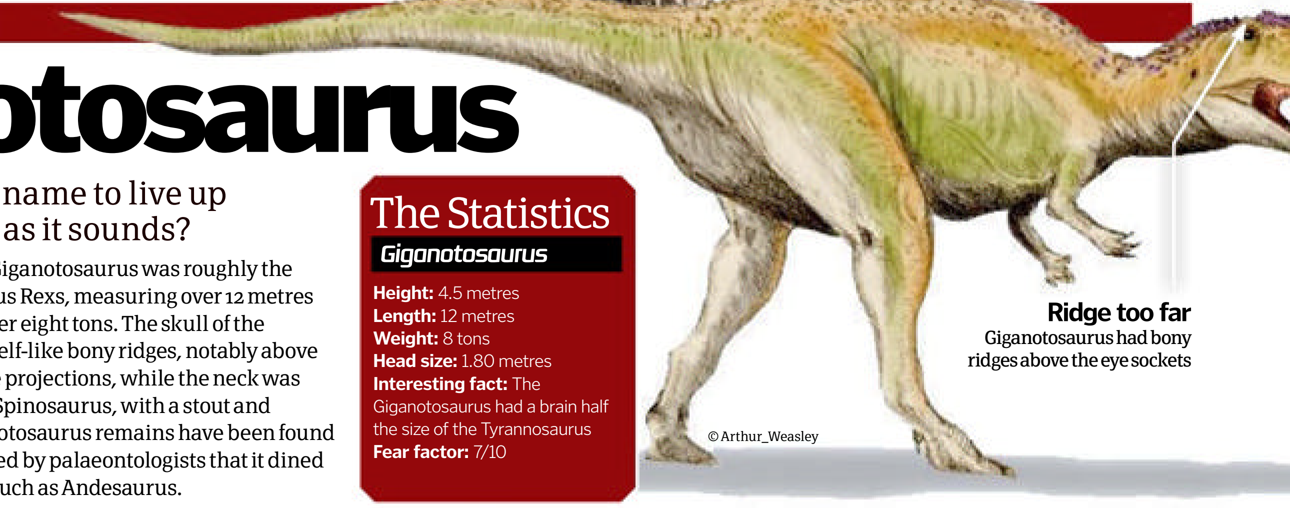
The dinosaur with a big name to live up to, but was it as colossal as it sounds?

Meaning 'giant southern lizard', the Giganotosaurus was roughly the same size as the largest Tyrannosaurus Rexs, measuring over 12 metres long, five metres tall and weighing over eight tons. The skull of the Giganotosaurus was adorned with shelf-like bony ridges, notably above the eye sockets and had low horn-like projections, while the neck was considerably thicker than that of the Spinosaurus, with a stout and powerful head supported by it. Giganotosaurus remains have been found in Argentina and it has been postulated by palaeontologists that it dined mainly on medium-sized dinosaurs such as Andesaurus.

The Statistics

Giganotosaurus

Height: 4.5 metres
Length: 12 metres
Weight: 8 tons
Head size: 1.80 metres
Interesting fact: The Giganotosaurus had a brain half the size of the Tyrannosaurus
Fear factor: 7/10

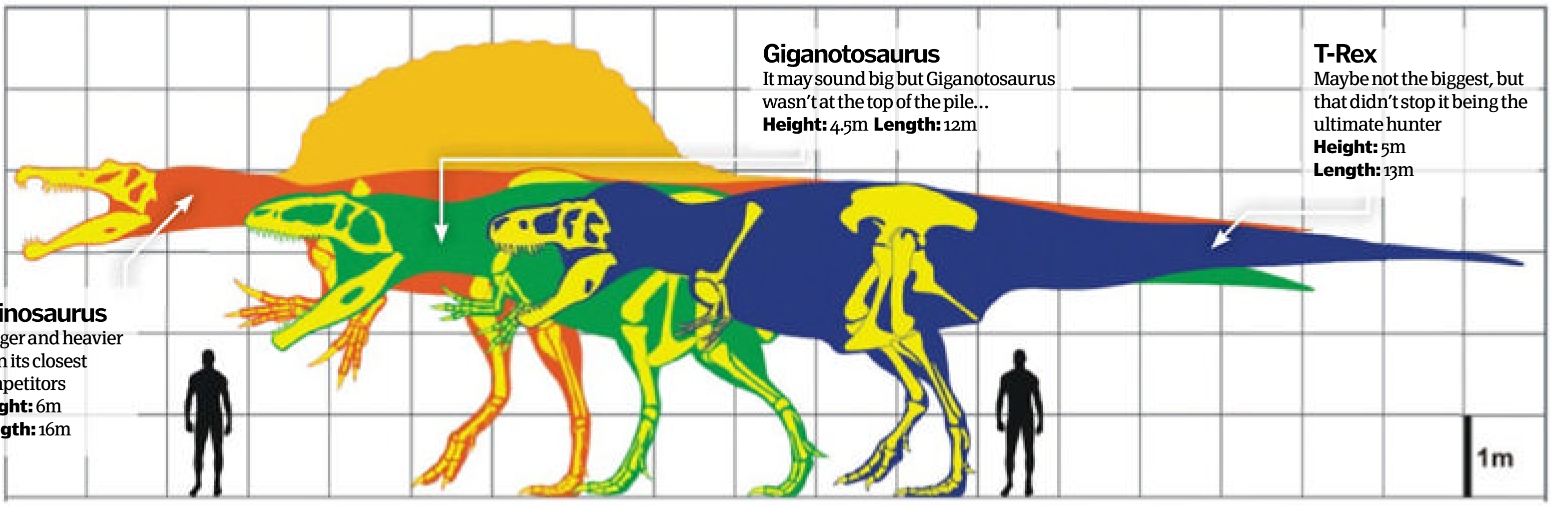


Ridge too far
Giganotosaurus had bony ridges above the eye sockets

© Arthur_Weasley

Size comparison

Who was the real king of the dinosaurs…



Giganotosaurus
It may sound big but Giganotosaurus wasn't at the top of the pile…
Height: 4.5m **Length:** 12m

T-Rex
Maybe not the biggest, but that didn't stop it being the ultimate hunter
Height: 5m
Length: 13m

Spinosaurus
Longer and heavier than its closest competitors
Height: 6m
Length: 16m

CARNIVORE 3

Carcharodontosaurus

Not the world's easiest name to pronounce…

Named in 1931, the African Carcharodontosaurus was a huge theropod with serrated teeth similar to the great white shark. The skull of the Carcharodontosaurus was very narrow although it reached up to 1.6 metres in length, while its body was taller at the back than at the front, giving it a low, streamlined physicality. The thigh muscles of the Carcharodontosaurus were some of the largest of any dinosaur and this, in partnership with its narrow streamlined frame and ferocious sharp teeth, made chasing down and devouring prey elementary. Arguably the quickest of the carnivorous theropods, the Carcharodontosaurus was a fearsome predator. Fossilised remains have been found in Morocco, Tunisia and Egypt

The Statistics

Carcharodontosaurus

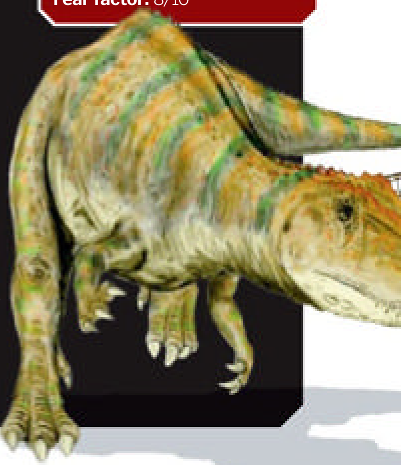
Height: 4 metres
Length: 11 metres
Weight: 6 tons
Head size: 1.60 metres
Interesting fact: The Carcharodontosaurus could run over 20mph
Fear factor: 8/10

This incredible beast was named after its deadly serrated teeth

© Didier Descovens 2010

Shark-like teeth
The serrations in the teeth are very similar to a shark's

© F.Fonseca



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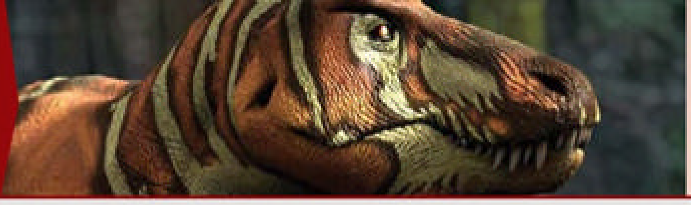
DID YOU KNOW?

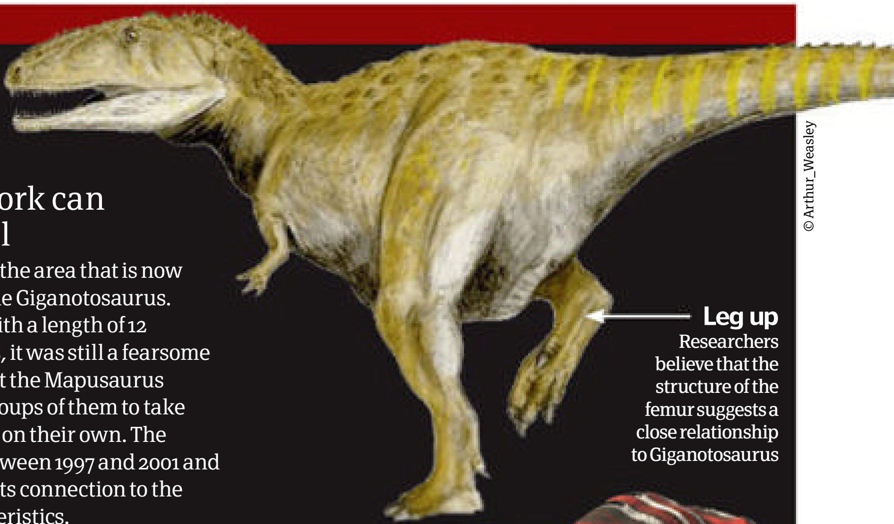


The biggest bite

The strength of the Tyrannosaurus's bite is estimated by palaeontologists to be greater than that of any other animal ever to live on Earth.

CARNIVORE 4

Mapusaurus



© Arthur_Weasley

Leg up
Researchers believe that the structure of the femur suggests a close relationship to Giganotosaurus

The Statistics

Mapusaurus

Height: 4 metres
Length: 12 metres
Weight: 4 tons
Head size: 1 metre
Interesting fact: Unlike other large theropod dinosaurs, Mapusaurus' would often hunt in groups
Fear factor: 6/10

The dinosaur that proved teamwork can be the best way to get a good meal

Dating from the late Cretaceous period and stalking the area that is now Argentina, the Mapusaurus was a close relative of the Giganotosaurus. Despite being one of the smaller giant carnivores, with a length of 12 metres, height of four metres and weight of four tons, it was still a fearsome predator. Interestingly, palaeontologists believe that the Mapusaurus would engage in group hunting activity, allowing groups of them to take down larger foes than they would be able to achieve on their own. The remains of the Mapusaurus were first excavated between 1997 and 2001 and now complete the majority of a full skeleton. Due to its connection to the Giganotosaurus, it shares many of the same characteristics.

CARNIVORE 5

Tyrannosaurus Rex

The most famous dinosaur of them all and the ultimate predator

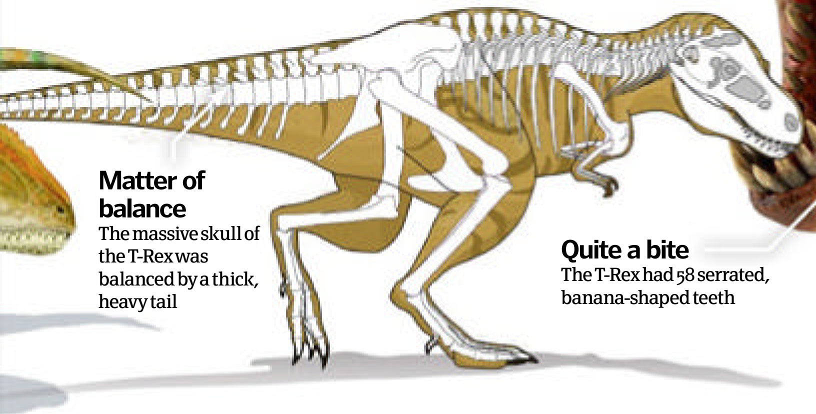
The T-Rex was one of the largest terrestrial carnivores in the world, with the estimated strength of its bite greater than that of any other animal that has ever existed on Earth. Standing at a height of five metres, measuring over 13 metres in length and weighing over nine tons, the T-Rex is considered to be one of the most fearsome hunters ever.

The body of the T-Rex was perfectly balanced, with a horizontal backbone positioned above the hips giving completely equal weight distribution. The head was also colossal, measuring 1.6 metres long and far bulkier than any other theropod, containing 58 serrated teeth and large forward-facing eye sockets giving it acute binocular vision. From fossilised remains of Tyrannosaurus faeces, palaeontologists have discovered that the T-Rex crushed bones of the prey it consumed. The T-Rex was prolific over the entire western North America.

A nice bit of colour… in case you didn't spot it running at you!

© Thinkstock

Good eyes
The T-Rex had binocular, colour vision



Matter of balance
The massive skull of the T-Rex was balanced by a thick, heavy tail

Quite a bite
The T-Rex had 58 serrated, banana-shaped teeth

The Statistics

Tyrannosaurus Rex

Height: 5 metres
Length: 13 metres
Weight: 9 tons
Head size: 1.6 metres
Interesting fact: The Tyrannosaurus Rex could consume 230kg of meat in a single bite
Fear factor: 10/10

Biggest ever land mammal

Find out how this prehistoric mega-mammal – eight times the size of a modern-day rhinoceros – used to live

Imagine a beast taller than a giraffe and heavier than two elephants. Paraceratherium was the dinosaur of its day. It filled the same ecological niche as the huge sauropod dinosaurs, like Diplodocus, that lived 120 million years earlier, roaming through lightly forested plains and eating the leaves of trees, which it stripped off the branches with its front teeth. Unlike the dinosaurs, Paraceratherium didn't have a long tail to counterbalance the weight of its neck and head. Instead, it had much more powerful neck muscles, anchored to tall extensions at the top of its spine. This brought its centre of gravity much farther forward, onto the front legs, resulting in a much stockier shape overall.

Paraceratherium lived during the Oligocene epoch, around 30 million years ago. The climate cooled suddenly during this period; Antarctica developed its ice cap for the first time and the Alps began to push upwards to form mountains. As the climate changed, the dense tropical forests were replaced with more open landscapes containing a mixture of trees and grass. These made it harder for medium-sized animals to hide from predators, so natural selection favoured ever-larger individuals able to fend off attacks. Along with competition between males for breeding rights, this drove the evolution of heavier grazing animals. The culmination of this was the Paraceratherium, which weighed a whopping 20 tons.

The largest predators at the time were a kind of marsupial hyena, no more than two metres (6.6 feet) long. An adult Paraceratherium was far too large to be troubled by these animals. Instead, they may have been eventually driven extinct by the rise of early elephant species. These would have knocked down the trees Paraceratherium relied on for food. As the grasslands expanded, Paraceratherium was replaced by smaller grazing mammals.

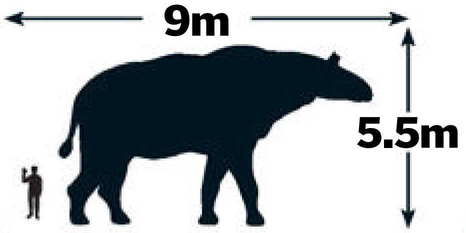
The problems with bone identification

The first Paraceratherium fossil bones were found in 1911 by the palaeontologist Clive Forster Cooper. Two years later, he found more bones he took to be from a related genus and named the animal Baluchitherium because the fossils were found in Baluchistan, in what is now Pakistan. In 1915, Aleksei Borissiak found a third set of bones and named the animal Indricotherium, after the Indrik, a monster from Russian folklore.

None of these fossil finds were anything like a full skeleton, and it can be very hard to decide whether you have found a completely new animal or just a larger example of an existing one based on a single neck vertebra. The scientific consensus is now that all three sets of fossils belong to the same genus, which is called Paraceratherium, because this was the first one to be described scientifically. To date, five species of Paraceratherium have been identified.

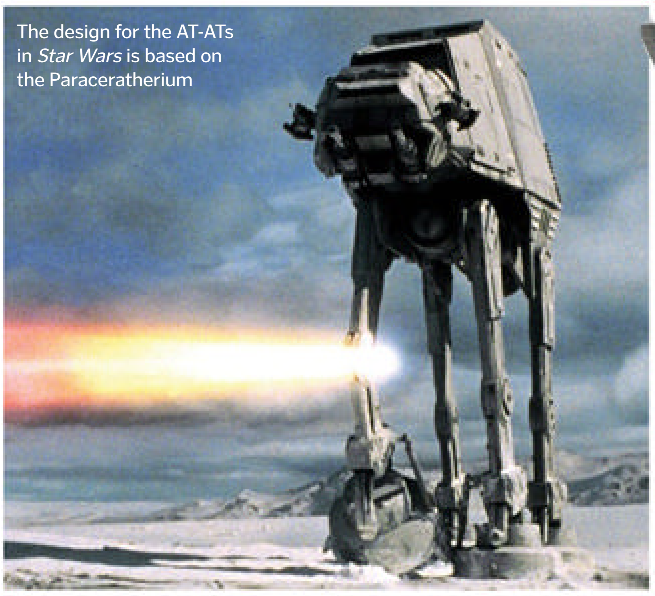
Size matters

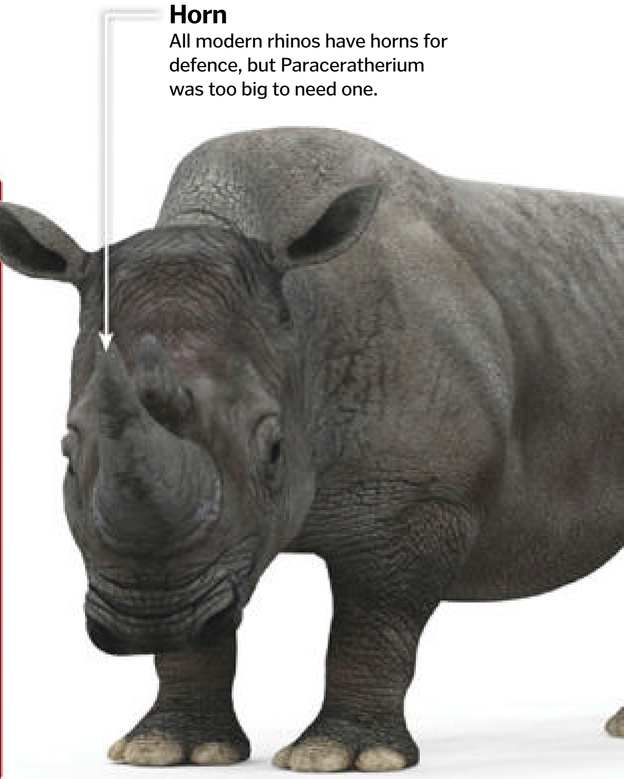
How would the Paraceratherium have measured up against a person?



In a galaxy far, far away...

When Phil Tippett was designing the special effects for *Star Wars Episode V: The Empire Strikes Back*, he needed a reference model for the giant mechanical AT-AT walkers that assault the rebel base on Hoth. Initially, his team studied elephants to animate the leg movements, but the final design is much taller and more menacing. That's because they are based on the Paraceratherium. The AT-ATs portrayed in the film are three times as tall as the prehistoric mammal, but the lumbering gait and joint articulation is probably very close to the way the real Paraceratherium would have moved around.


The design for the AT-ATs in *Star Wars* is based on the Paraceratherium


Horn
All modern rhinos have horns for defence, but Paraceratherium was too big to need one.

5 TOP FACTS
MEGAFAUNA

Toxodon

1 This 1.5-ton hoofed animal looked like a hornless rhinoceros, but had much larger front legs than hind legs. Herds of them roamed South America 20,000 years ago.

Diprotodon

2 The 'hippopotamus wombat' was the largest marsupial ever. 3m (9.8ft) long and weighing 2.8 tons, its fossils may have inspired Aboriginal legends of the 'bunyip'.

Megatherium

3 This ground sloth weighed about four tons. It only went extinct 10,000 years ago and, at the time, only the Columbian and woolly mammoths were larger.

Deinotherium

4 Although they aren't closely related, Deinotherium looked like an overgrown elephant, but with larger front legs and tusks pointing down. It lived about 7 million years ago.

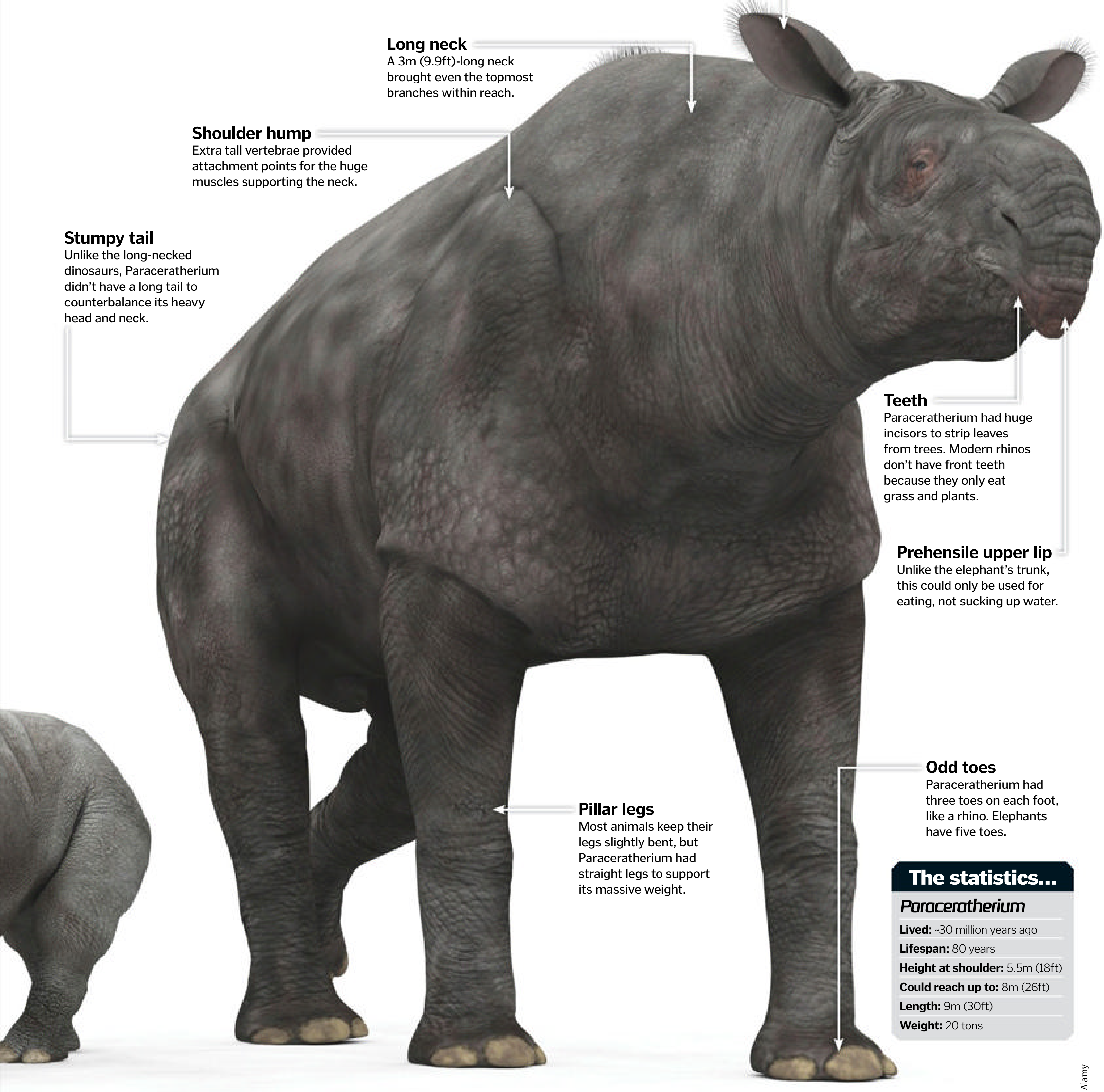
Woolly mammoth

5 At 3.4m (11.2ft) tall and weighing six tons, these ice age relatives of the elephant had tusks up to 4.2m (13.8ft) long that could weigh over 90kg (200lb).

DID YOU KNOW? *Paraceratherium was bigger than Diplodocus; although the dino was longer, Paraceratherium was bulkier*

Anatomy of a mega-mammal

Paraceratherium may be related to the modern rhino, but there are some sizable differences, as we highlight here...



Mystery ears
Soft ears don't fossilise, but it's possible that Paraceratherium had large flapping ears to keep cool like today's elephants.

Long neck
A 3m (9.9ft)-long neck brought even the topmost branches within reach.

Shoulder hump
Extra tall vertebrae provided attachment points for the huge muscles supporting the neck.

Stumpy tail
Unlike the long-necked dinosaurs, Paraceratherium didn't have a long tail to counterbalance its heavy head and neck.

Teeth
Paraceratherium had huge incisors to strip leaves from trees. Modern rhinos don't have front teeth because they only eat grass and plants.

Prehensile upper lip
Unlike the elephant's trunk, this could only be used for eating, not sucking up water.

Odd toes
Paraceratherium had three toes on each foot, like a rhino. Elephants have five toes.

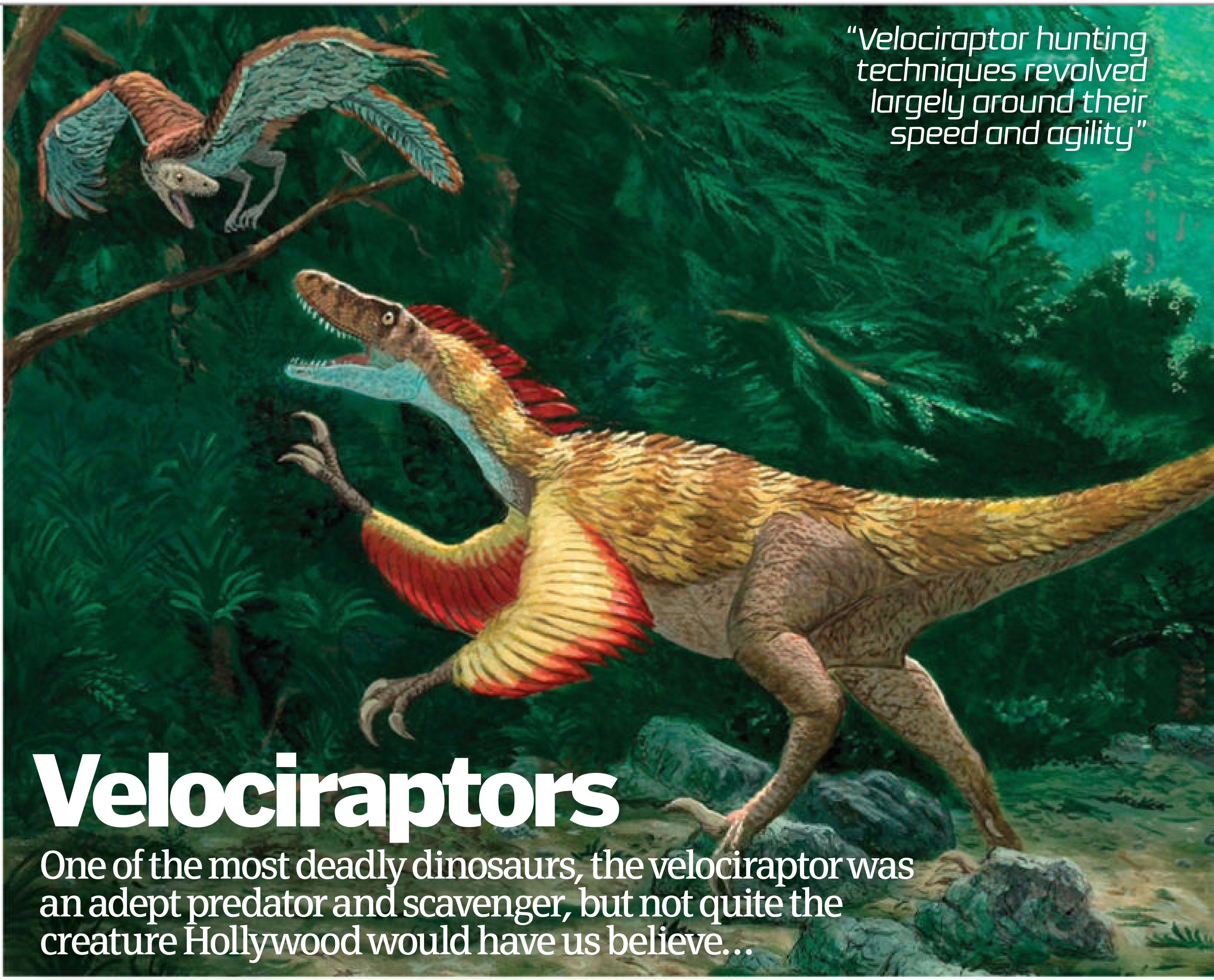
Pillar legs
Most animals keep their legs slightly bent, but Paraceratherium had straight legs to support its massive weight.

The statistics...

Paraceratherium

Lived: ~30 million years ago
Lifespan: 80 years
Height at shoulder: 5.5m (18ft)
Could reach up to: 8m (26ft)
Length: 9m (30ft)
Weight: 20 tons

© Alamy



"Velociraptor hunting techniques revolved largely around their speed and agility"

Velociraptors

One of the most deadly dinosaurs, the velociraptor was an adept predator and scavenger, but not quite the creature Hollywood would have us believe…

Velociraptors have been ingrained in public consciousness since the 1993 movie *Jurassic Park* showcased them as the most fearsome of apex predators. Smart, lethal and bloodthirsty, the velociraptors of the film arguably stole the show. However, the movie was famed for its indulgence of artistic licence, with palaeontologists bemoaning the lack of historical accuracy throughout the movie.

So what were these dinosaurs really like? Velociraptor, of which there are two verified species – V mongoliensis and V osmolskae, was a genus of dromaeosaurid ('running lizard') theropod dinosaur that lived in the Late Cretaceous period, about 75-71 million years ago. They were two metres (6.6 feet) long, just under a metre (three feet) high, feathered and bipedal, running on two of their three toes per foot. They were native to modern-day central Asia (notably Mongolia), where they built large, ground-based nests to protect their young.

Velociraptors, though often living in close proximity to one another, were largely solitary and, while certain finds suggest they could have teamed up while chasing their quarry, they were not pack hunters, with evidence showing they would fight among themselves for feeding rights. In addition, their staple diet consisted of animals of equal size and weight to themselves or those smaller than them, with very little evidence suggesting they would attempt to bring down larger dinosaurs, such as the Tyrannosaurus rex à la *Jurassic Park*.

Velociraptor hunting techniques revolved largely around their speed and agility. They could accelerate up to 64 kilometres (40 miles) per hour and pounce long distances, as well as grip prey firmly with their unique, sickle-shaped claws (notably their enlarged 'killing claw'). These traits were partnered with a tendency to ambush prey, rather than tackle their victims face on or from long range (see the 'Slash or subdue?' boxout for more).

Interestingly, however, while there's no doubt that velociraptors hunted live prey, unearthed fossilised evidence suggests they were also incredibly active scavengers, with the species frequently feeding on carrion (pterosaur bones have been found in velociraptor guts, for instance) and carcasses left over by other predators.

Velociraptors died out along with the remaining species of dromaeosauridae in the run up to, and as a result of, the Cretaceous-Tertiary mass-extinction event that occurred approximately 65.5 million years ago. Despite this, elements of their anatomy and appearance can still be seen today – albeit in heavily evolved forms – in many species of bird.

5 TOP FACTS
VELOCIRAPTOR MYTHS

Feathered fiend

1 Contrary to popular depictions of velociraptors in films such as *Jurassic Park*, they would have in fact been covered in feathers, a trait that's been passed down to today's birds.

Size matters

2 Another falsehood perpetuated by Hollywood movies is the size of velociraptors. Far from being over three metres (9.9 feet) long, they were much closer to two metres (6.6 feet).

Pack hunters

3 Velociraptors didn't tend to hunt in packs. Evidence suggests various individuals did chase prey at the same time, but would then squabble among each other for 'first dibs'.

American citizens

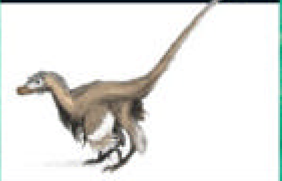
4 Another myth perpetuated by the *Jurassic Park* franchise is that velociraptors lived in what is now the Americas. In fact, remains have only ever been discovered in central Asia.

'Philosoraptor'

5 Unlike the super-intelligent velociraptors depicted in *Jurassic Park* – eg opening closed doors with their claws – they were likely only as smart as a primitive opossum.

DID YOU KNOW? *Modern-day hawks and eagles attack their prey in a similar way to velociraptors*

The statistics…



Velociraptor

Group: Theropod

Family: Dromaeosauridae

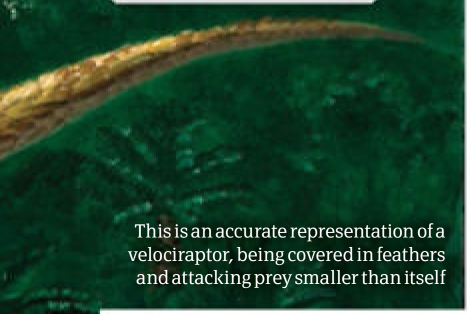
Length: 2m (6.6ft)

Height: 0.8m (2.5ft)

Weight: 113kg (200lb)

Location: Asia, eg Mongolia

Period: Late Cretaceous



This is an accurate representation of a velociraptor, being covered in feathers and attacking prey smaller than itself

Slash or subdue?

Did velociraptors use their sickle-shaped claws to disembowel prey or for some other purpose?

The majority of non-avian theropod dinosaurs are characterised by razor-sharp serrated teeth and talon-like recurved claws, the velociraptor being no exception. Armed with a bounty of claws on both its hands and feet, the velociraptor at first glance seems to be the perfect killing machine, capable of rapidly chasing down prey before shredding their flesh with one of their knife-like tools. Well, that was at least the commonly accepted theory among palaeontologists until late in 2011, before a new study by a team of international dinosaur experts suggested an entirely different use for them.

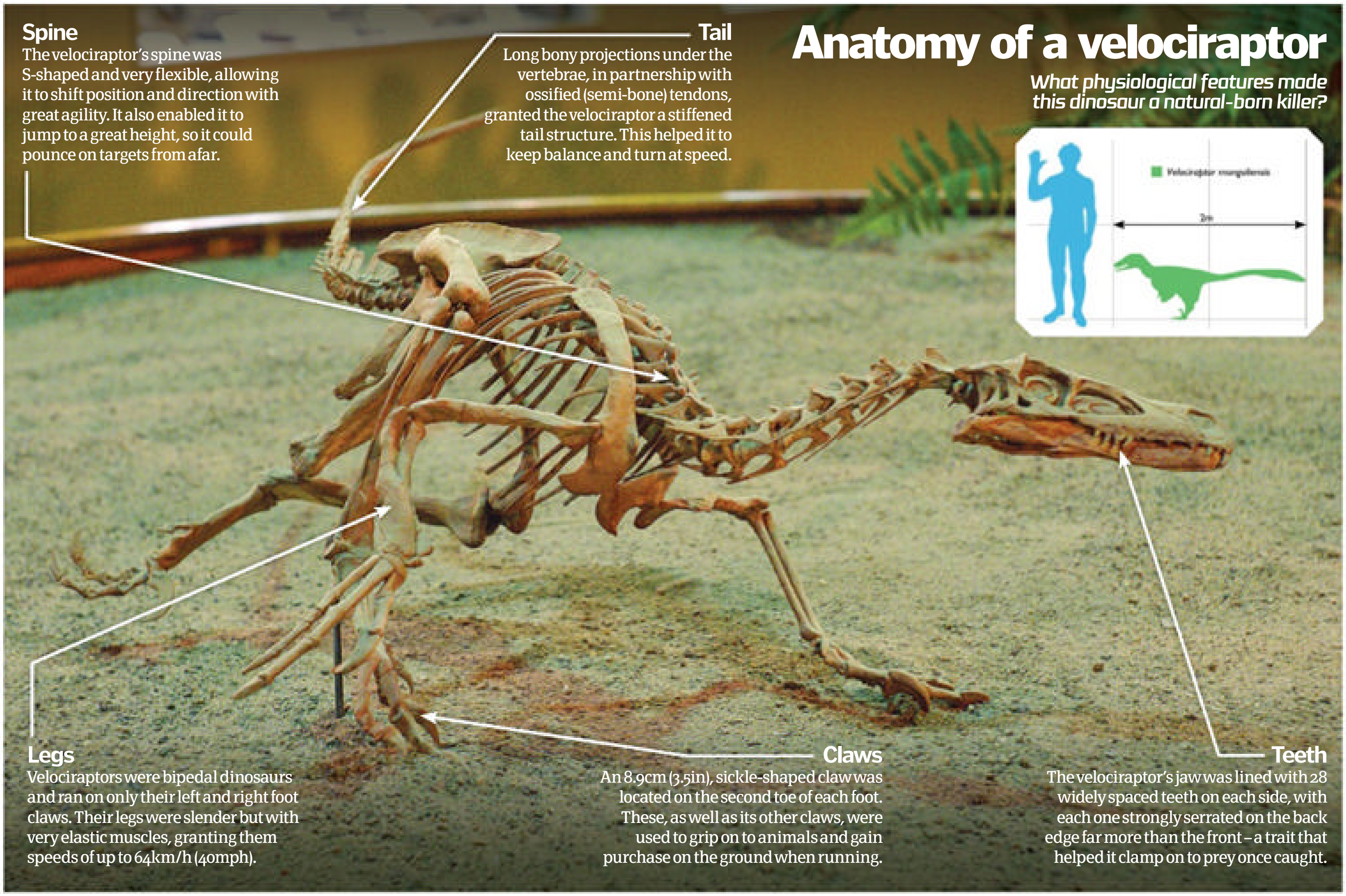
The study suggested that far from their claws – specifically the velociraptor's much-touted 'killing claws' – being used to shred and slice prey in order to kill them prior to consumption, they were far more likely to be used in a similar way to the talons of modern-day hawks and eagles. This entails the birds using their talons as a gripping tool, snaring prey of a lesser body size, pinning them down with their own body weight and then often consuming them live with their beaks.

This theory is seemingly backed up by the velociraptor's feet showing morphology consistent with a grasping function, supporting a prey immobilisation model rather than the originally assumed combative one.

A fossilised claw from a velociraptor. Recent evidence has emerged that has challenged the idea that this was used as a slashing weapon

Anatomy of a velociraptor

What physiological features made this dinosaur a natural-born killer?



Spine

The velociraptor's spine was S-shaped and very flexible, allowing it to shift position and direction with great agility. It also enabled it to jump to a great height, so it could pounce on targets from afar.

Tail

Long bony projections under the vertebrae, in partnership with ossified (semi-bone) tendons, granted the velociraptor a stiffened tail structure. This helped it to keep balance and turn at speed.

Legs

Velociraptors were bipedal dinosaurs and ran on only their left and right foot claws. Their legs were slender but with very elastic muscles, granting them speeds of up to 64km/h (40mph).

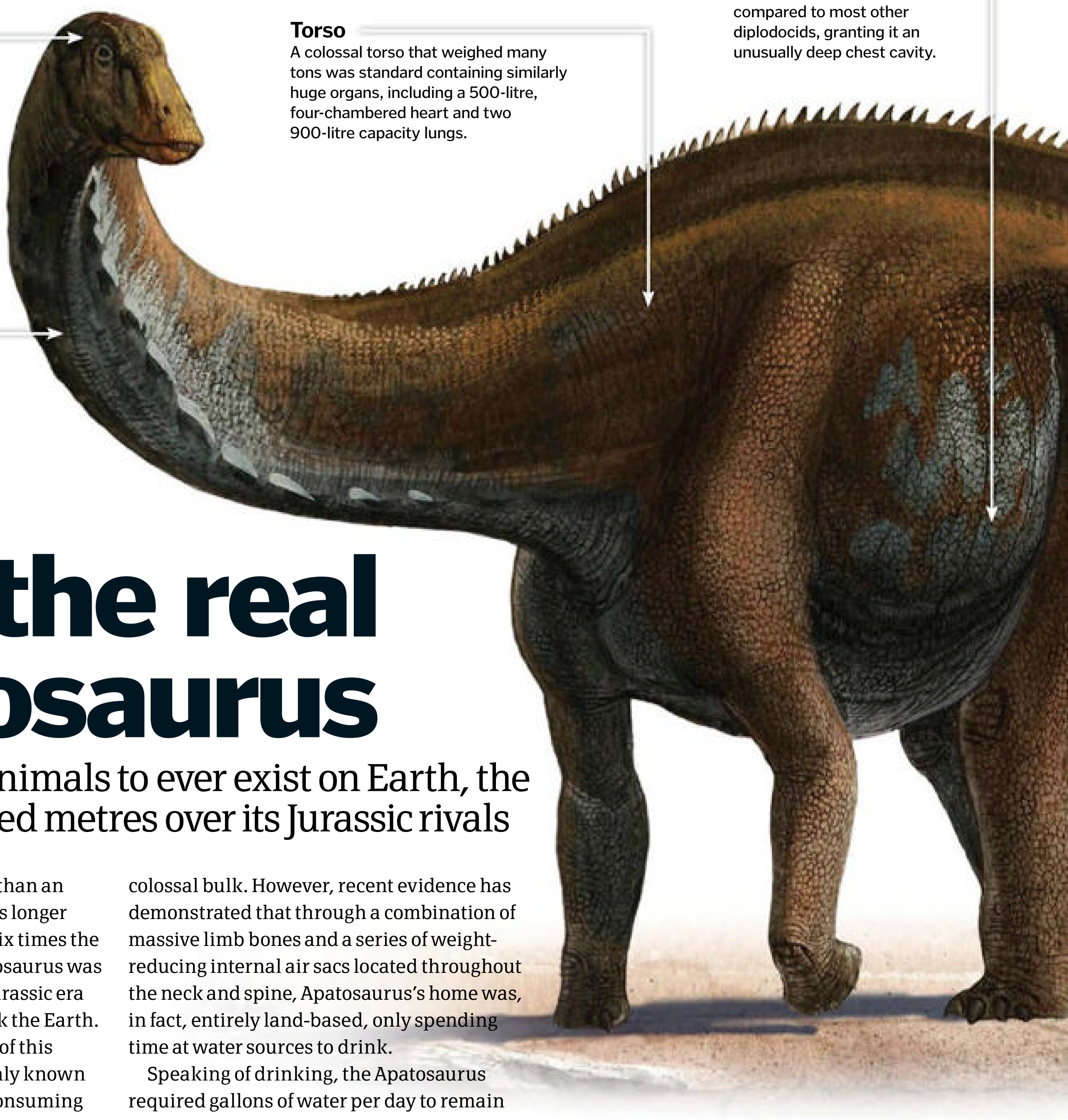
Claws

An 8.9cm (3.5in), sickle-shaped claw was located on the second toe of each foot. These, as well as its other claws, were used to grip on to animals and gain purchase on the ground when running.

Teeth

The velociraptor's jaw was lined with 28 widely spaced teeth on each side, with each one strongly serrated on the back edge far more than the front – a trait that helped it clamp on to prey once caught.

© SPL; Ben Townsend; Matt Martyniuk



Head
Apatosaurus had a deep, slender skull filled with long peg-like teeth. These broad, rounded teeth were excellent at stripping off leaves from branches.

Torso
A colossal torso that weighed many tons was standard containing similarly huge organs, including a 500-litre, four-chambered heart and two 900-litre capacity lungs.

Ribs
Apatosaurus possessed incredibly long, robust ribs compared to most other diplodocids, granting it an unusually deep chest cavity.

Neck
As with other sauropods, the Apatosaurus's neck vertebrae were deeply bifurcated, carrying paired spines. The neck was also filled with many weight-saving air sacs.

Meet the real Brontosaurus

One of the largest animals to ever exist on Earth, the Apatosaurus towered metres over its Jurassic rivals

Around four times heavier than an African elephant, five times longer than your car and almost six times the height of a full-grown human, Apatosaurus was one of the largest dinosaurs of the Jurassic era and one of most gigantic to ever walk the Earth.

As is typical with large dinosaurs of this period, Apatosaurus (once mistakenly known as Brontosaurus) was a herbivore, consuming vast quantities of foliage and grasses over the lands that now form modern-day North America. Interestingly, despite its size, its name is derived from the Greek 'apate' and 'saurus', which translate as 'deception lizard' – a name bestowed by its original discoverer, American palaeontologist Othniel Charles Marsh.

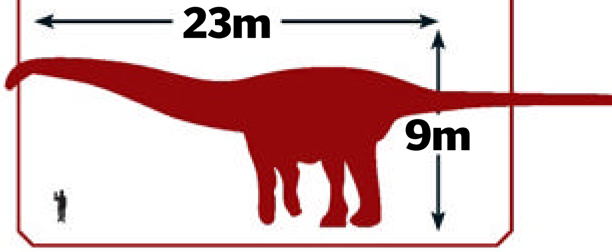
Prior to the 1970s, Apatosaurus, along with many other sauropods, were considered largely aquatic creatures that relied on being partially submerged in swamps and lakes to remain stable – a view seemingly confirmed by their colossal bulk. However, recent evidence has demonstrated that through a combination of massive limb bones and a series of weight-reducing internal air sacs located throughout the neck and spine, Apatosaurus's home was, in fact, entirely land-based, only spending time at water sources to drink.

Speaking of drinking, the Apatosaurus required gallons of water per day to remain healthy, while it also needed to process vast amounts of food, spending a large proportion of each day grazing. It did this with few predators, as only the largest carnivorous dinosaurs had any chance of bringing down an Apatosaurus, largely thanks to its size. It also had a deadly weapon in its tail, which was capable of being swung at great velocity at any foes.

Despite its defensive prowess, however, the Apatosaurus could not battle off extinction, with it falling to a medium-sized extinction event around 150 million years ago.

Apatosaurus vs human

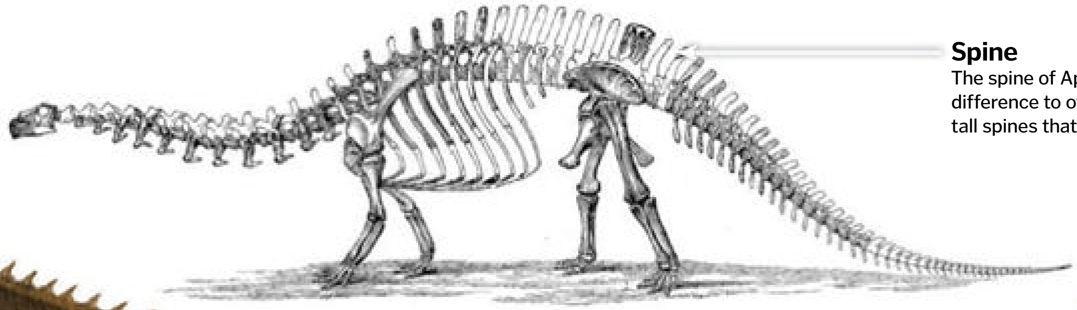
How would this enormous dinosaur have sized up to a person?



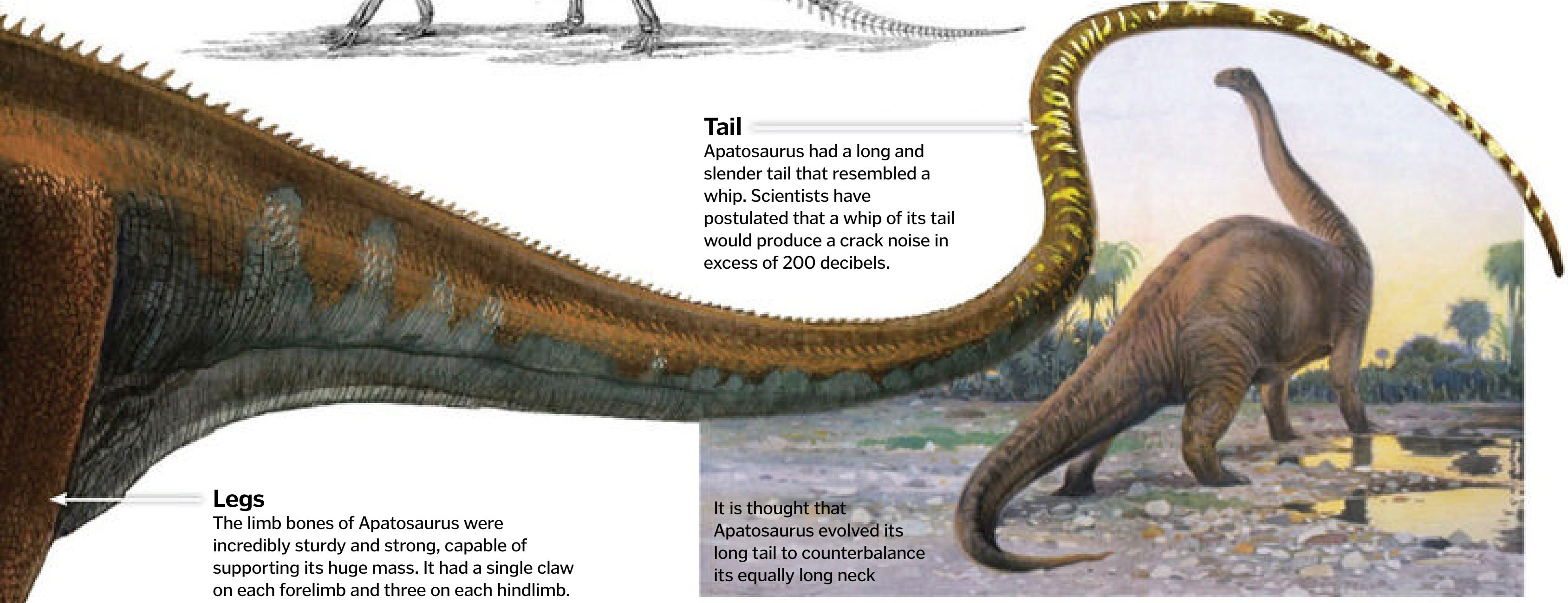
THE STATS
APATOSAURUS

HEIGHT 9m
WEIGHT 30,000kg
TIMEFRAME 154-150MYA
LENGTH 23m
LIFE EXPECTANCY Up to 100yrs
DISCOVERED 1877

DID YOU KNOW? *Apatosaurus skeleton fragments have been found in Wyoming, Colorado, Oklahoma and Utah*



Spine
The spine of Apatosaurus was interesting in its difference to other sauropods, possessing incredibly tall spines that made up half its total height.



Tail
Apatosaurus had a long and slender tail that resembled a whip. Scientists have postulated that a whip of its tail would produce a crack noise in excess of 200 decibels.

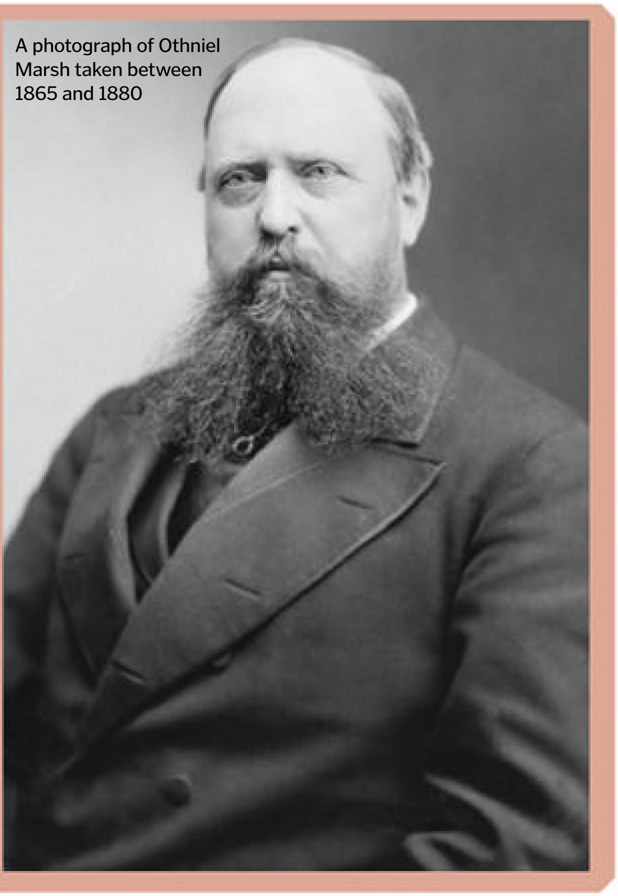
Legs
The limb bones of Apatosaurus were incredibly sturdy and strong, capable of supporting its huge mass. It had a single claw on each forelimb and three on each hindlimb.

It is thought that Apatosaurus evolved its long tail to counterbalance its equally long neck

The bone wars

During the beginning of the golden age of modern palaeontology, two prominent American palaeontologists, Edward Cope and Othniel Marsh, had a falling out over excavated dinosaur remains, with the men then proceeding to attempt to beat each other to unearth and describe new species of dinosaur. In this rush to become the foremost palaeontogist of the age, Marsh described first in 1877 and then later in 1879 two supposedly separate species of dinosaur. He named the first one Apatosaurus and called the second one Brontosaurus.

Following this, the name of Brontosaurus became world famous, with a complete skeleton mounted and displayed in the Peabody Museum, Yale, under the Marsh title in 1905. However, Marsh in his haste had made a terrible mistake. The Brontosaurus was actually just a fully-grown Apatosaurus and, since the Apatosaurus had been described first in 1877, its name took precedent, with 'Brontosaurus' made officially redundant in the early-20th century. Interestingly, however, as the Brontosaurus name had become firmly fixed in the public consciousness, it remained far more popular and is still in use to this day to the chagrin of many dinosaur experts.

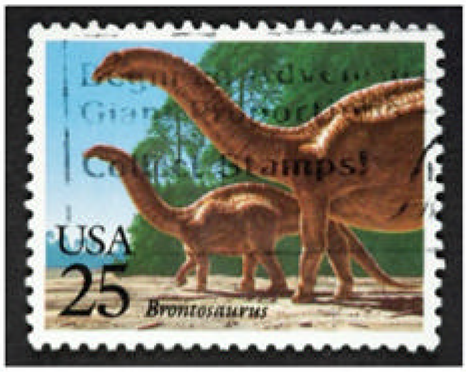

A photograph of Othniel Marsh taken between 1865 and 1880

Stamp scandal

In 1989, the US Post Office decided to release a special edition set of four stamps depicting famous dinosaurs. These included a Tyrannosaurus, Stegosaurus, Pteranodon and, interestingly, a Brontosaurus.

The latter was included despite the fact that, as noted in 'The bone wars' boxout, the name 'Brontosaurus' had been made officially redundant in the early-20th century.

The fallout from this was massive, with many palaeontologists and dinosaur enthusiasts accusing the US Post Office of promoting 'scientific illiteracy' and re-opened a bone war-style feud between others. Indeed, even the celebrated palaeontologist Stephen Jay Gould got involved, writing a famous defence of the Brontosaurus name in his *Natural History* magazine piece 'Bully for Brontosaurus'.



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Ankylosaurus

A club-wielding brute of a creature, this tough dino had the power to break bones

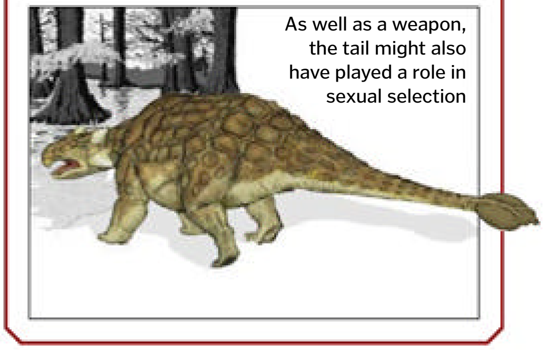
Ankylosaurus was one of the largest ankylosaurs, a genus of armoured dinosaurs that lived throughout North America between 75 and 65.5 million years ago. Famous for both its brutal tail-mounted club and its immense bone plate armour, the Ankylosaurus was a defensive titan, capable of fending off rivals many times its size.

Ankylosaurus's focus on defence was born out of its herbivorous nature, with its entire body geared towards the consumption of foliage. From its low-slung body, rows of leaf-shaped cropping teeth, short front legs, wide feet and cavernous stomach, the Ankylosaurus was the consummate browser, devouring vegetation whole with little shredding or chewing. Indeed, studies have indicated that the skull and jaw of the Ankylosaurus were structurally tougher than many similar, contemporary dinosaurs.

In fact, evidence suggests that Ankylosaurus – and ankylosaurs in general – were adept survivors. But despite their impressive armour, weaponry and sustainable diet, they could not cope with the Cretaceous-Tertiary extinction event that wiped out all terrestrial dinosaurs approximately 65.5 million years ago. Only a few fossils of this prehistoric herbivore have been excavated to date – most coming from the Hell Creek Formation in Montana, USA.

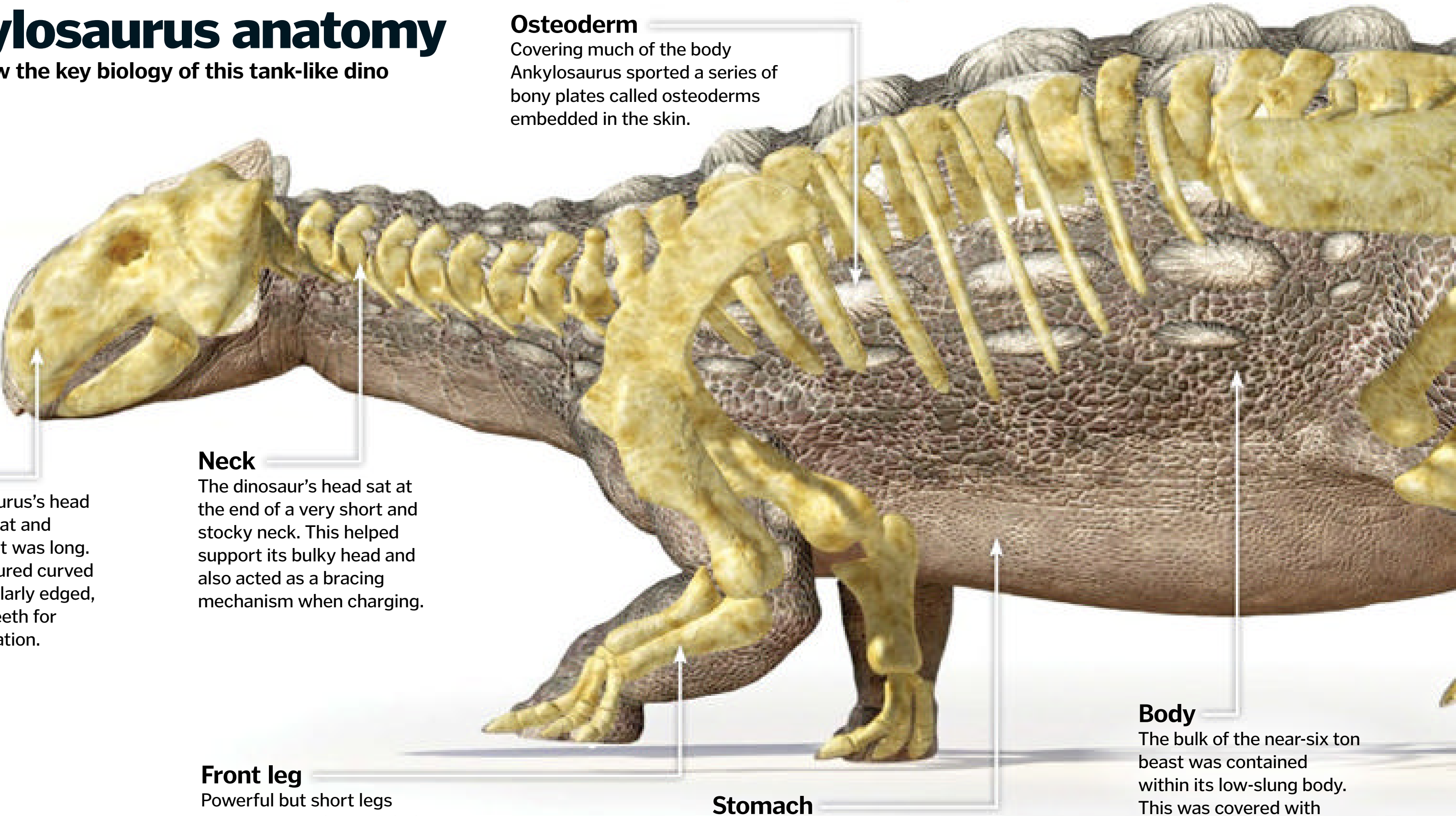
Club members only

The well-known tail club of the Ankylosaurus was one of the most lethal weapons sported by any dinosaur. The club was made from several large bone plates called osteoderms that were fused into the last few vertebrae of the animal's tail. Behind these vertebrae several others lined with thick, partially ossified tendons completed the club's handle, resulting in a structure that, when swung, was capable of dealing out a lot of damage. Indeed, a study in 2009 suggested that the tail clubs of fully grown ankylosaurs could easily crush and break bone with a force capable of caving in an assailant's skull. Whether or not the animal purposely aimed the club to cause damage remains unclear at this point.


As well as a weapon, the tail might also have played a role in sexual selection

Ankylosaurus anatomy

Get to know the key biology of this tank-like dino



Osteoderm
Covering much of the body Ankylosaurus sported a series of bony plates called osteoderms embedded in the skin.

Head
The Ankylosaurus's head was square, flat and broader than it was long. The jaws featured curved rows of irregularly edged, leaf-shaped teeth for tearing vegetation.

Neck
The dinosaur's head sat at the end of a very short and stocky neck. This helped support its bulky head and also acted as a bracing mechanism when charging.

Front leg
Powerful but short legs supported the front half of the animal. The wide foot area of these forelegs granted good traction and stability.

Stomach
The only part of the dinosaur that was unarmoured, the underbelly hung low to the ground. Predators would try to tip ankylosaurs over to access this weak point.

Body
The bulk of the near-six ton beast was contained within its low-slung body. This was covered with armoured bone plating and topped with spines.

THE STATS ANKYLOSAURUS

HEIGHT 2.5m

LENGTH 10m

LIVED 75-65.5 MYA

WIDTH 1.8m

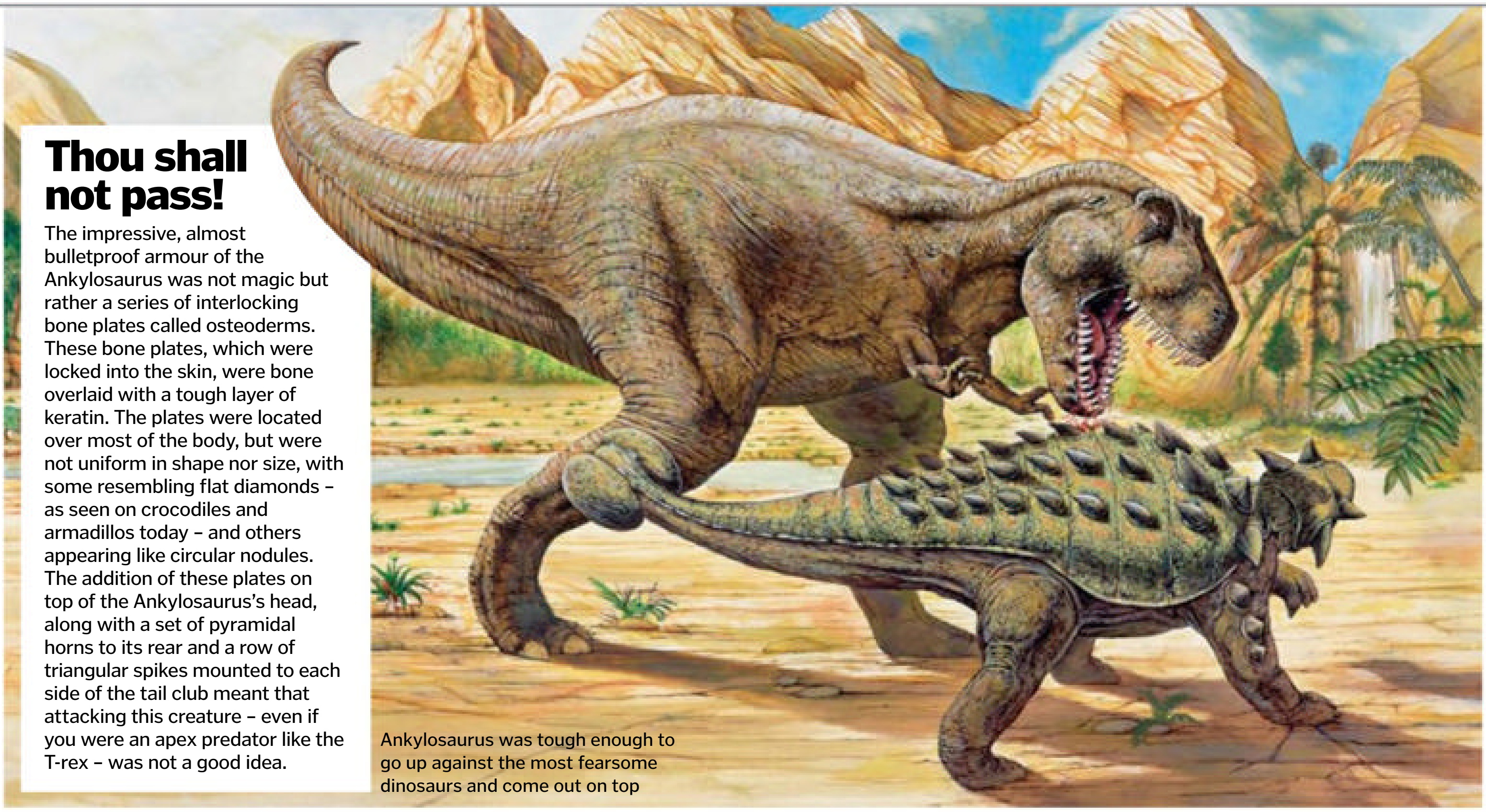
WEIGHT 4,000-7,000kg

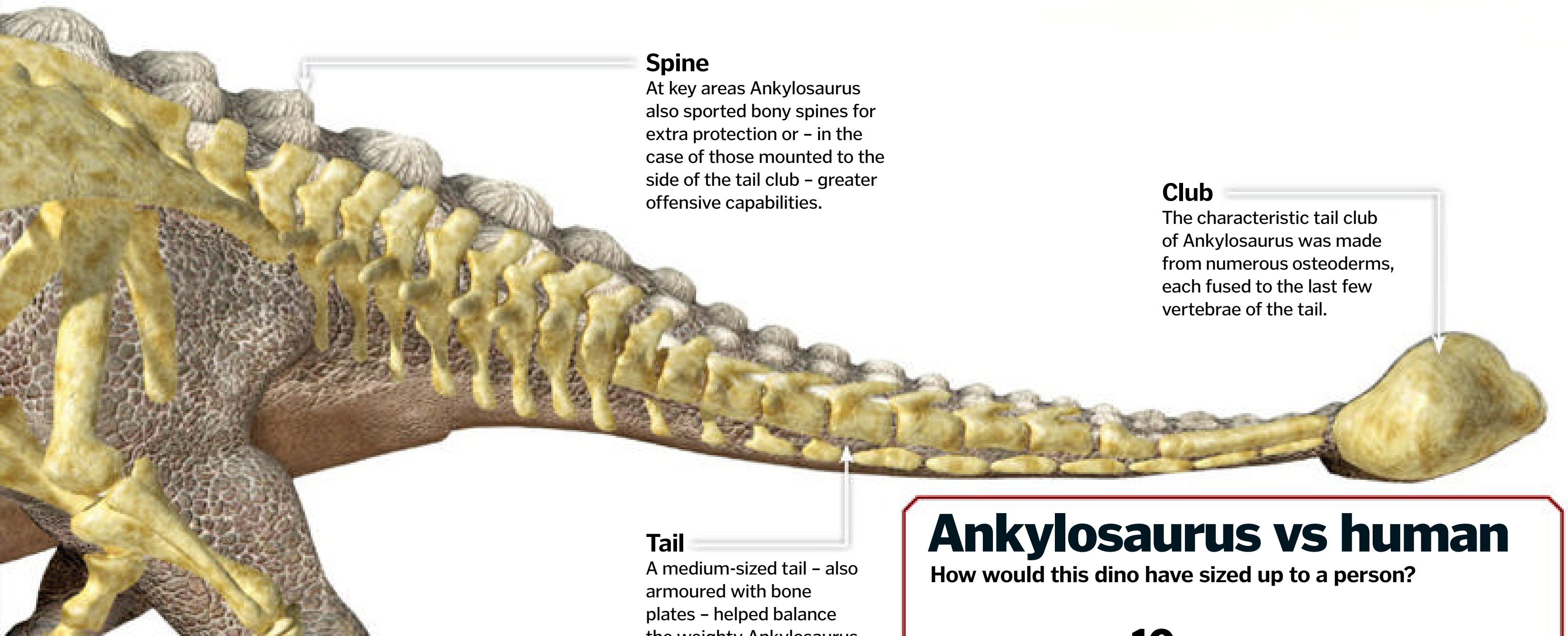
FIRST FOSSIL FOUND 1906

DID YOU KNOW? *Interestingly the earliest specimens of ankylosaurs we have found did not possess a tail club*

Thou shall not pass!

The impressive, almost bulletproof armour of the Ankylosaurus was not magic but rather a series of interlocking bone plates called osteoderms. These bone plates, which were locked into the skin, were bone overlaid with a tough layer of keratin. The plates were located over most of the body, but were not uniform in shape nor size, with some resembling flat diamonds – as seen on crocodiles and armadillos today – and others appearing like circular nodules. The addition of these plates on top of the Ankylosaurus's head, along with a set of pyramidal horns to its rear and a row of triangular spikes mounted to each side of the tail club meant that attacking this creature – even if you were an apex predator like the T-rex – was not a good idea.


Ankylosaurus was tough enough to go up against the most fearsome dinosaurs and come out on top



Spine
At key areas Ankylosaurus also sported bony spines for extra protection or – in the case of those mounted to the side of the tail club – greater offensive capabilities.

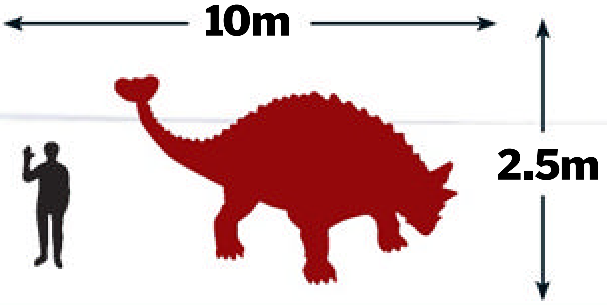
Club
The characteristic tail club of Ankylosaurus was made from numerous osteoderms, each fused to the last few vertebrae of the tail.

Tail
A medium-sized tail – also armoured with bone plates – helped balance the weighty Ankylosaurus and provided the power to cause maximum damage with its club.

Rear leg
Equally powerful – if not more so – but longer than the Ankylosaurus's forelegs, the rear legs reached up to about 1.7m (5.6ft) at the hip.

Ankylosaurus vs human

How would this dino have sized up to a person?



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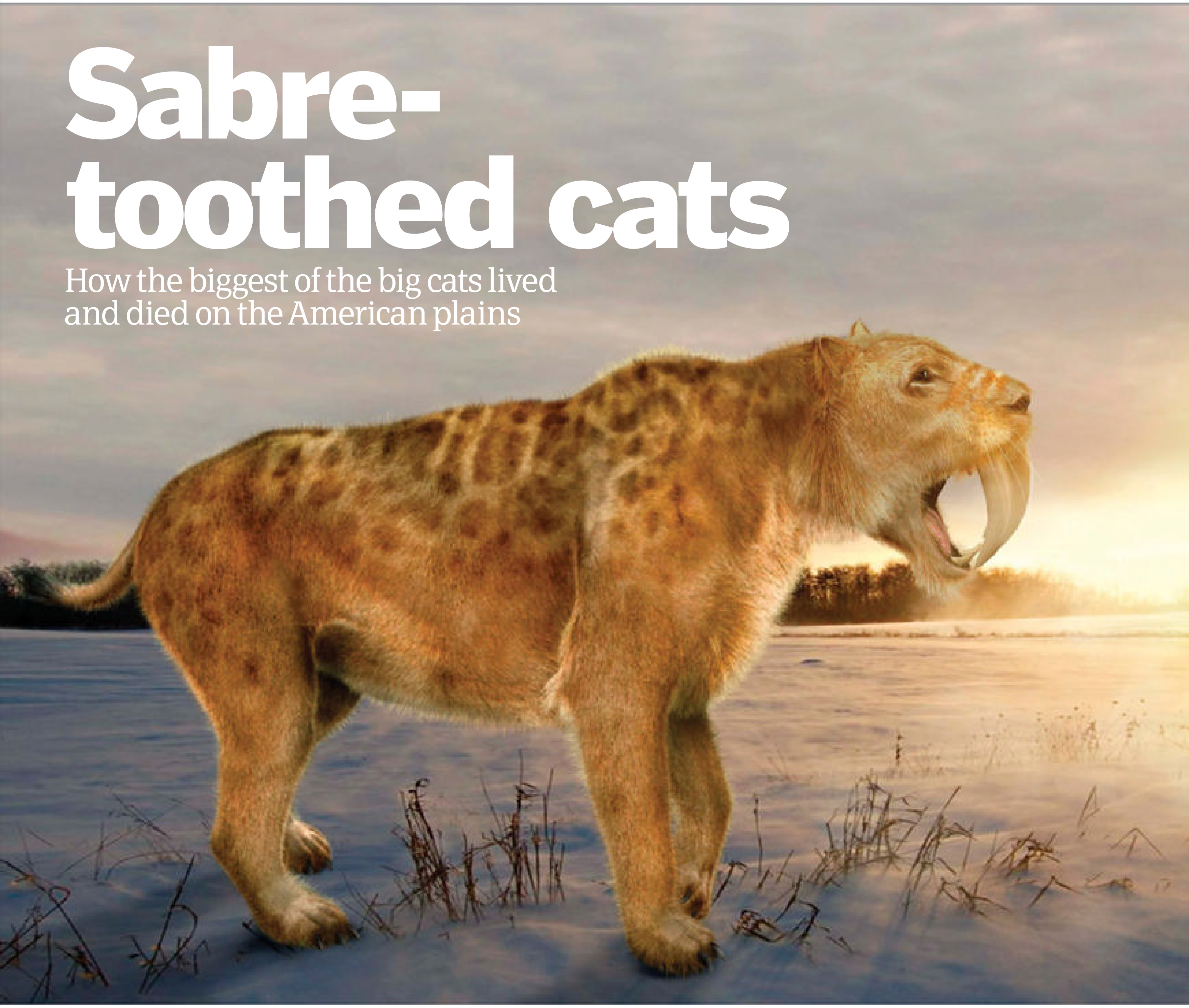
Sabre-toothed cats

How the biggest of the big cats lived and died on the American plains



It's a common misnomer, but the sabre-toothed tiger never existed. What most people think of when someone mentions a sabre-tooth is Smilodon, a very successful cat of which there were three to five different species. Although believed to have originated in Africa and Eurasia, these felines lasted the longest in the Americas, right up to the end of the last ice age 10,000 years ago. Smilodon gracilis was a relatively small feline weighing about the same as a human. It died out around 500,000 BCE having been usurped by its descendant, the significantly larger Smilodon fatalis, an animal weighing in at 160-280 kilograms (350-620 pounds) – about the same as today's Siberian tiger. But its close relative Smilodon populator is the biggest big cat on record, a whopping 220-360 kilograms, 1.4 metres (4.6 feet) at the shoulder and up to 2.6 metres (8.5 feet) long, with its characteristic upper canines reaching an eye-watering 30 centimetres (12 inches)! And unfortunately for us (or perhaps for Smilodon populator), this sabre-toothed cat was around long enough to see Homo sapiens appear on the scene.

Smilodon populator was a similarly social carnivore to African lions and hunted in small groups, but its muscular build and limb length meant that it ambushed prey rather than chasing it down. It preferred the large mammals of the time that were common to the Americas: juvenile mammoths and mastodons, American camels, ground sloths and

KEY DATES
BIG CAT DIARY

35 MYA
Nimravus was an ambush cat that weighed around 30kg (66lb). It had a similar evolution but wasn't a true sabre-tooth.

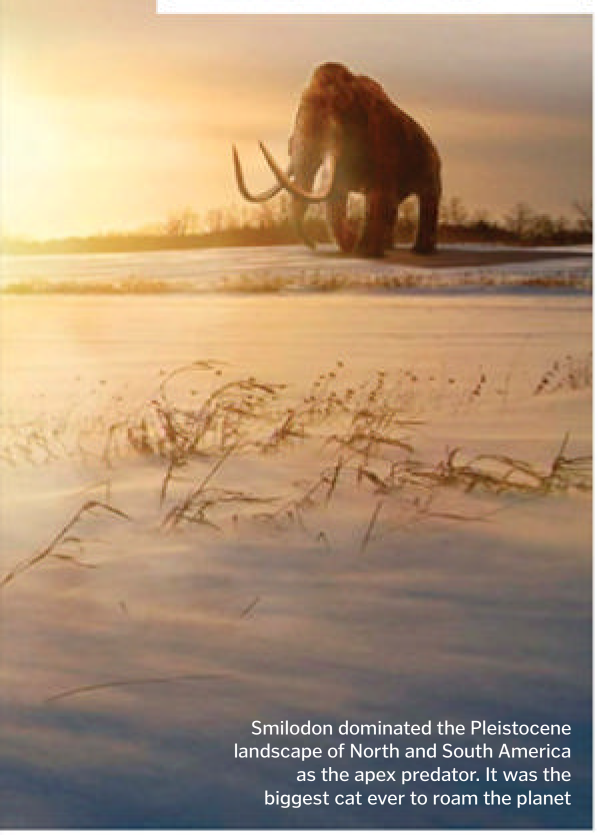
32 MYA
A relative to Nimravus, Dinictis (right) was an arboreal feline that looked similar to a leopard.

17 MYA
There were two species of Prosansanosmilus, which prowled a warmer Europe for about a million years.

5 MYA
Homotherium, aka the scimitar cat (left), was found all over Europe, Asia and the Americas.

2.5 MYA
It seems fitting that the biggest sabre-tooth, Smilodon populator, was the last on the scene and the last to die out.

DID YOU KNOW? *The name Smilodon is derived from the Greek for chisel- or knife-tooth*



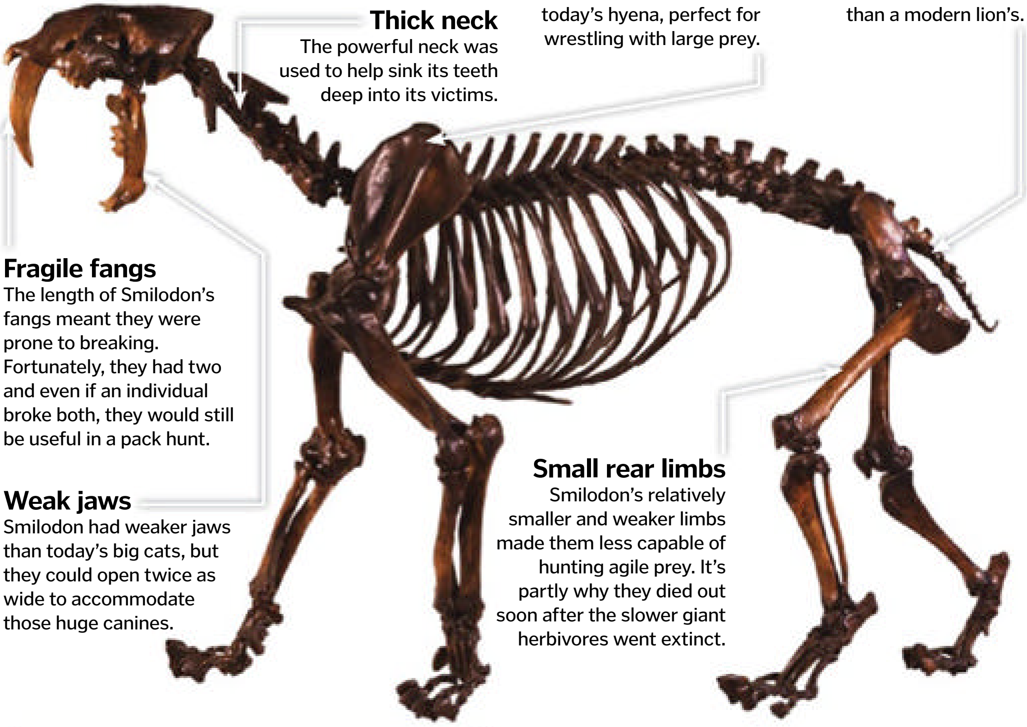
Smilodon dominated the Pleistocene landscape of North and South America as the apex predator. It was the biggest cat ever to roam the planet

macrauchenia (extinct llama-like mammal). Several Smilodon would use their combined body weight to drag prey down and subdue them, before using their sharp teeth like daggers to inflict mortal wounds to the neck.

It's likely that Smilodon populator preyed on early humans on occasion, but it's just as likely that the success of Homo sapiens, and our competition for the megafauna they hunted, ultimately sounded the major death knell for this legendary feline species.

Sabre-tooth skeleton

Explore one of these ancient feline predators from the inside out



Thick neck
The powerful neck was used to help sink its teeth deep into its victims.

Broad shoulders
Smilodon populator had especially powerful forelimbs, built more like today's hyena, perfect for wrestling with large prey.

Bob tail
Sabre-tooths had a tail, but it was stubby and more like a bobcat's than a modern lion's.

Fragile fangs
The length of Smilodon's fangs meant they were prone to breaking. Fortunately, they had two and even if an individual broke both, they would still be useful in a pack hunt.

Weak jaws
Smilodon had weaker jaws than today's big cats, but they could open twice as wide to accommodate those huge canines.

Small rear limbs
Smilodon's relatively smaller and weaker limbs made them less capable of hunting agile prey. It's partly why they died out soon after the slower giant herbivores went extinct.

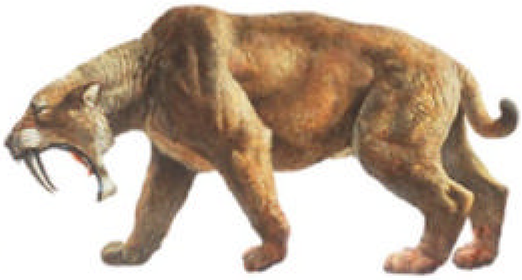
Palaeontologists have assembled hundreds of prehistoric animals from the bones found at La Brea

Big cat boneyard

The Page Museum, Los Angeles, is located on a site of great palaeontological significance. It's home to La Brea Tar Pits, an ancient death-trap for megafauna that roamed the area 10,000-40,000 years ago. Here, subterranean bitumen leaked to the surface creating a gloopy bog of tar. Mammals like the mastodon (an elephant ancestor) and other giant herbivores stumbled into the morass and drowned. Predators such as Smilodon were attracted by the alarm calls of struggling prey and converged on what seemed to be an easy meal, only to become trapped themselves. The asphalt from the tar pit was being used by settlers 300 years ago, but it wasn't until 1875 that William Denton discovered La Brea's scientific importance. Since excavations started in 1913, over 3.5 million fossils have been found here, including 2,500 sabre-toothed cats.

Why did cats evolve sabre teeth?

Sabre teeth are a great example of convergent evolution: many species evolved this same trait independently around this time. So what was the benefit of these deadly weapons? The apex predators of this era were equipped with disproportionately huge fangs because, as simple as it sounds, the animals they hunted were much bigger. Modern big cats like the African lion throttle their prey by crushing the windpipe – a fine tactic to finish a dainty gazelle, but if you're attacking beasts significantly beyond your weight category – like the woolly mammoth – hanging onto their throat until they suffocated wasn't an option. Smilodon used their dagger-like canines like an assassin, surprising its intended meal by stabbing at the throat or ripping its soft belly, then retreating and allowing the victim to weaken before moving in for the kill.



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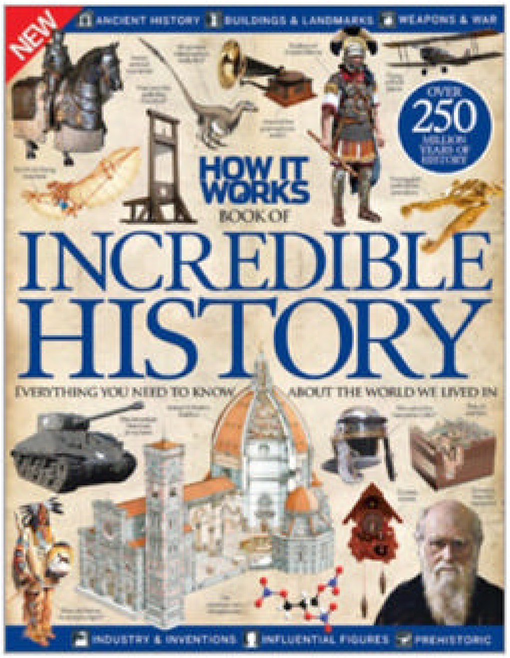

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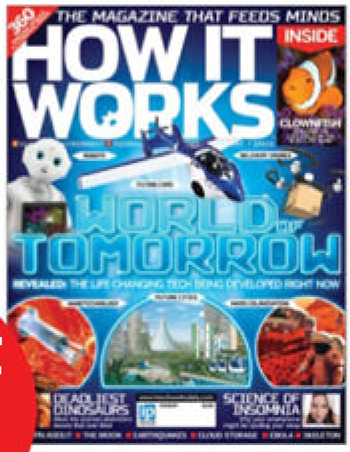
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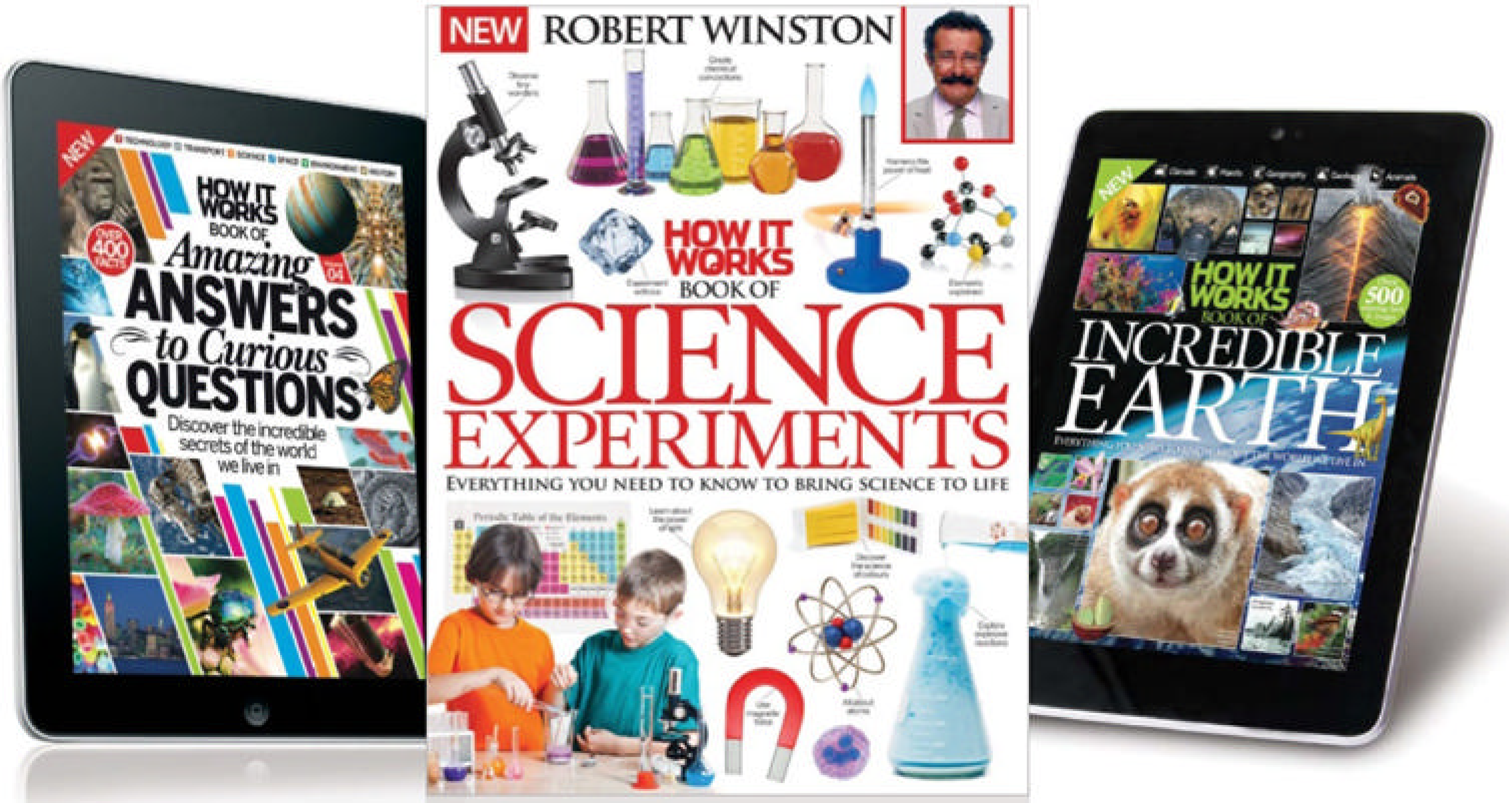

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